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NOTES ON THE STRATIGRAPHY OF THE UPPER CRETACEOUS FORMATIONS OF TEXAS AND ARKANSAS[1]

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ABSTRACT

The stratigraphic relations of the formations of the Gulf series (Upper Cretaceous) in Texas and Arkansas are briefly described in the text and are graphically represented in a correlation chart. Two new units, the Tokio and Ozan formations, are recognized (in collaboration with C. H. Dane) in the Arkansas section. A new name, Gober, is proposed for a tongue of the Austin chalk, which was previously incorrectly correlated with the Annona chalk. A new formation name, Olmos, is given to the "coal series," in the Rio Grande section in Maverick County, Texas. Several important unconformities are recognized in the Gulf series. The Gulf series is shown to be separated from the Comanche series below, and from the Midway (Eocene) above, by important unconformities.

An attempt is made to show the age relations of the formations by means of heavy numbered lines. The divergence of these lines shows the thickening, and their convergence the thinning, of the series. The thinning of the series is attributed in part to actual thinning of the deposits and in part to the presence of unconformities.

INTRODUCTION

This paper presents in summary form the results of studies of the stratigraphy of the Gulf series (Upper Cretaceous) carried on in a somewhat desultory way since 1911 in Texas, Oklahoma, and Arkansas. These results are based on my personal observations in the field, on fossils in the laboratory, and on all published data. No comprehensive study of well data in the Coastal Plain east and southeast of the belt of outcrop of the Gulf series has as yet been undertaken.

Mr. H. D. Miser, of the Geological Survey, who has been studying the stratigraphy of the Comanche series and the lower part of the Gulf series in Arkansas and Oklahoma, and Mr. Carle H. Dane, also of the Geological Survey, who has recently been conducting a critical study of the stratigraphy of the Cretaceous formations of southwestern Arkansas, have co-operated with me in establishing the age and

[1] Read before the Association at the Dallas meeting, March 27, 1926. Manuscript received by the editor August 26, 1926. Published by permission of the Director of the U. S. Geological Survey.

stratigraphic relations of the Cretaceous formations in those areas to the corresponding ones in Texas. I have been in frequent consultation with Dr. T. W. Stanton of the Geological Survey, with particular reference to the relation of the Gulf series to the underlying Comanche series, and with Dr. J. B. Reeside, also of the Geological Survey, with particular reference to the significance in correlation of several ammonite species. Great benefit has been derived from my association with the geologists of the Bureau of Economic Geology and Technology of Texas, and with the many geologists connected with the development of the petroleum industry of the region, who have given me their generous and hearty co-operation.

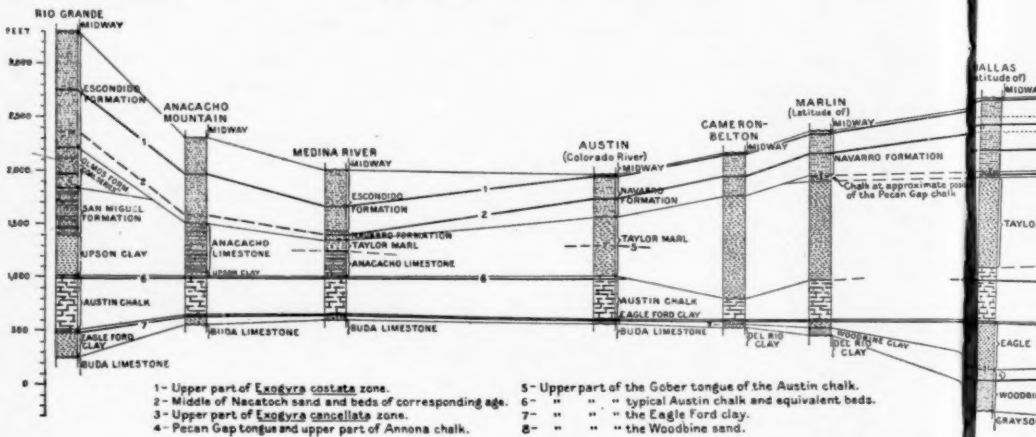
The area treated is so large, and so much depends on detailed work in critical local areas, many of which have not as yet been studied in sufficient detail, that the results here presented must be regarded as tentative and subject to revision. In a paper of this scope it is obviously impossible to present the evidence in support of many of the conclusions stated, but more detailed treatment will be given to the subject in a paper now in preparation.

The formations of the Gulf series are treated in the order of their age from the oldest to the youngest. The Woodbine sand, the basal formation of the series, is briefly described, and its relations to formations below and above it are stated. The Eagle Ford clay, the Austin chalk and its equivalents, the Taylor marl and its equivalents, and the Navarro and Escondido formations and their equivalents are successively treated in a similar way.

WOODBINE SAND

Character.—The Woodbine sand, the oldest formation of the Gulf series, consists chiefly of irregularly bedded sand which was deposited in shallow marine and brackish water, but interbedded with the sand are films, lenses, and layers of clay, in places attaining a thickness of many feet. A considerable part of the formation in northeastern Texas and in Arkansas is characterized by the presence of water-laid volcanic material.

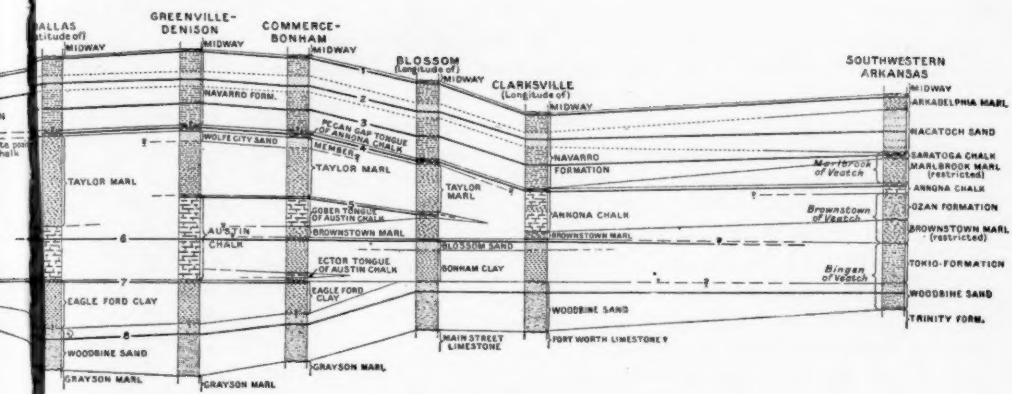
Stratigraphic relations.—In Texas the formation rests unconformably upon beds belonging to the Washita group, the uppermost group of the Comanche series. From Dallas County northward the deposit immediately beneath the Woodbine is at most places the Grayson marl member of the Denison formation, the youngest division of the Washita, but locally the Woodbine transgresses the Grayson and rests upon the underlying Main Street limestone member of the Denison. From Dallas County southward to and including Bell County, the Woodbine rests at most places upon marl which is in reality the southward extension of the Grayson marl, but from McLennan County southward this marl is generally regarded as forming a part of the Del Rio clay. At a few places in McLennan and Denton counties beds of limestone resembling the Buda limestone, which farther south is the topmost formation of the Washita, occur in the top of the Grayson immediately beneath the Woodbine. It has not been determined whether these Buda-like limestones are lentils in the Grayson marl or whether



CORRELATION OF THE UPPER CRETACEOUS (…RIES) …

By L. W. Stephenson, in colla…with C. …

PLATE 1



US (…RIES) FORMATIONS IN TEXAS AND ARKANSAS

coll… with C. H. Dane in Arkansas

they were once continuous above the marl and were later cut out by erosion at the places where the Woodbine rests directly on the marl. From Williamson County southward the Woodbine rests upon the Buda limestone.

The pronounced character of the unconformity between the Comanche series and the Gulf series in Texas is evidenced by the contact relationships as exposed in places in Travis, Bell, Hill, Denton, and other counties. Conglomeratic material occurs at the base of the Woodbine in places, and at one exposure on Aquilla Creek west of Hillsboro in Hill County the contact cuts across the bedding of the Grayson marl, showing a vertical unevenness in the eroded Grayson surface of at least 5 feet within a horizontal distance of 150 feet.

A forthcoming paper by H. D. Miser, C. S. Ross, and L. W. Stephenson will show that in southeastern Oklahoma the Woodbine transgresses from west to east successively lower and older divisions of the Comanche, until in Arkansas the Woodbine rests upon the Trinity, the lowest division of the Comanche series (see Plate 1). The time represented by the Woodbine-Comanche erosion unconformity in Texas, though not a major hiatus, was probably of considerable length, but in Oklahoma and Arkansas the overlap just described indicates that from west to east this time interval becomes successively longer, until in Arkansas it embraces nearly all of Comanche time. The unconformity is therefore of regional extent and is in no sense a minor or local feature. In the light of this fact the Woodbine formation may logically be regarded as the beginning of Gulf series sedimentation.

The contact between the Woodbine sand and the overlying Eagle Ford clay is sharp and definite at the few places at which I have examined it, and the two formations may be everywhere unconformable. At none of the localities examined, however, is there an accumulation of coarse material in the nature of a conglomerate at the base of the Eagle Ford as would be expected in view of the hard fossil and concretionary material in the Woodbine formation that might have been reworked in the base of the Eagle Ford. Further field study may show that conglomeratic material does occur at this contact. There is less physical evidence of an unconformity between the Woodbine and Eagle Ford than there is between the Woodbine and the underlying Comanche series.

Clay of Woodbine age south of Hill County.—The Woodbine sand has heretofore been regarded as extending only as far south in Texas as Hill County, where the formation was believed to pinch out and disappear. South of Hill County the Eagle Ford clay was supposed to rest unconformably on beds belonging to the upper part of the Comanche series, without any beds of Woodbine age intervening. Mr. R. L. Cannon[1] recently informed me that he had examined gray non-calcareous non-sandy clay which forms a part of the Woodbine formation in Hill County, and had traced clay of this character southward through McLennan, Bell, and Williamson counties to the vicinity of Austin in Travis County. He concluded that the lower part of the Eagle Ford clay in the counties south of Hill County, as heretofore mapped, is in reality clay of Woodbine age. In order to de-

[1] Oral communication.

termine whether or not I could agree with Mr. Cannon I visited several Woodbine localities in Hill County west of Hillsboro and west of Abbott, and one locality in the northern part of McLennan County. In Hill County beds of clay such as he described occur in both the upper and lower parts of the Woodbine formation, and these are associated with beds of a more or less sandy character. At the McLennan County locality clay of the Woodbine type rests unconformably upon the Grayson marl, at the top of which is a thin layer of white nodular limestone. The Woodbine in this area is unconformably separated from the Grayson marl of the Comanche series below; it is also sharply separated from the overlying Eagle Ford clay of the Gulf series, and this contact may mark an unconformity.

I then examined the section between Belton and Temple in Bell County and found a body of clay 20 or 25 feet thick, practically free from sand but otherwise identical in character with the Woodbine clay in Hill and McLennan counties, resting unconformably on marl of the Grayson type, here included in the Del Rio clay, and overlain with a sharp contact by basal sandy limestone of the Eagle Ford formation. This upper contact undulates somewhat, but the basal limestone of the Eagle Ford is scarcely conglomeratic. I did not have an opportunity to examine the clay in the section at Austin, which Mr. Cannon correlates with the Woodbine. These observations seem to show that clay of Woodbine age does extend much farther south than has heretofore been supposed.

The Woodbine sand in Arkansas.—In Arkansas the lower part of the Bingen sand of Veatch forms the eastward continuation of the Woodbine sand, and this lower division is unconformably overlain by gravels, sands, and clays (including the Tokio sand member of Miser and Purdue) which form the upper part of the Bingen of Veatch. The upper part of the "Bingen" contains fossils, which according to our present understanding of their range, indicate post-Eagle Ford age, and if this correlation is correct, the unconformity between the upper and lower parts of the "Bingen" represents the time interval of the Eagle Ford, and is therefore a stratigraphic break of sufficient magnitude to necessitate dividing the "Bingen" into two formations. The lower of these formations is in reality the Woodbine sand, and should be so designated, and in Hempstead and Pike counties the upper, exclusive of a basal gravel bed, has been called by Miser and Purdue[1] the Tokio sand member of the "Bingen formation." From Tokio in Hempstead County eastward the Tokio, including the basal gravel just mentioned, consists chiefly of sand and gravel and comprises all of the "Bingen formation" above the unconformity, but toward the west the sands appear to tongue into a section composed chiefly of clay, and in a recently issued press bulletin[2] Dane proposes that the name Tokio formation, rather than Tokio sand, be used for the sands, clays, and gravels composing the upper of the two formations. Miser and Dane have agreed that the heavy bed of gravel which underlies the Tokio sand of Miser and Purdue as originally defined,

[1] Hugh D. Miser and A. H. Purdue, "Gravel Deposits of the Caddo Gap and DeQueen Quadrangles, Arkansas," *U. S. Geol. Survey Bull. 690* (1919), p. 23.

[2] *U. S. Geol. Survey Press Bull. No. 8823*, July, 1926.

and which is in reality a basal conglomerate, should be included in the Tokio formation, and this definition has been adopted in this paper.

Buried coastward extension of the Woodbine.—The Woodbine sand extends coastward beneath the Eagle Ford clay, and is the principal oil-bearing formation in the oil fields along the Mexia-Powell fault zone as far south as Groesbeck. A small outcrop of sand believed to represent the Woodbine occurs at the Palestine salt dome, 6 miles west by south of Palestine, in Anderson County, about 85 miles east of the main belt of outcrop of the formation. The sand here has been lifted fully 5,000 feet above its normal position by the structural movements associated with the formation of the salt dome.

Transgressive character of the Woodbine sea.—A theory has recently been advanced by Dr. Gayle Scott,[1] that the Woodbine sand was deposited in a retreating or regressive sea, marking the close of Comanche sedimentation, rather than in an advancing or transgressive sea recording the beginning of Gulf series sedimentation. His conclusions appear to me to be based largely upon unproved assumptions as to the manner in which sediments of the Woodbine type are deposited. I know of no positive paleontologic evidence in support of the theory, and the following physical facts may be cited as evidence that the Woodbine sea advanced across the area following a period of emergence and erosion:

1. In Texas a pronounced unconformity exists between the Woodbine sand and the Washita group of the Comanche series, on which it rests.

2. The Woodbine transgresses from west to east through Oklahoma and Arkansas onto successively lower formations of the Comanche series, until in Arkansas it rests upon about the middle part of the Trinity sand, and lowermost division of the Comanche series. The unconformity at the base of the Woodbine in Arkansas therefore represents nearly all of Comanche time.

3. The Woodbine sand has a maximum thickness in northeastern Texas of 500, perhaps as much as 600, feet. All agree that the sands, clays, and subordinate lignites composing it were laid down in shallow water or in swamps only slightly above sea-level. The only way that so great a thickness of shallow-water deposits could accumulate would be for the area to subside continuously or at frequent intervals as deposition proceeded. In this connection it is apropos to suggest that the deposits laid down along the shore line of a retreating sea would be immediately exposed to the destructive forces of erosion and would in all probability be destroyed before they could be covered and protected by the deposits of a later transgressing sea.

EAGLE FORD CLAY

Character.—The Woodbine sand is overlain in Texas by the Eagle Ford clay, which consists chiefly of dark, more or less carbonaceous, clay, with calcareous concretions and subordinate layers of platy limestone. Fish remains, in the form of disseminated scales, small fragments of bones, and some teeth, are characteristic

[1] Gayle Scott, "The Woodbine Sand of Texas Interpreted as a Regressive Phenomenon," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10 (1926), pp. 613–24.

and in places the clay is definitely bituminous. From Dallas County northward the clay contains a smaller percentage of fish remains and is in general smoother and less granular in texture than it is south of that county.

Distribution and stratigraphic relations.—As previously stated, the contact between the Eagle Ford clay and the underlying Woodbine sand is sharp, and may be an unconformity. The Eagle Ford, however, is not coextensive with the Woodbine sand, for in northeastern Texas the Eagle Ford has not been observed farther east than Lamar County, whereas the Woodbine extends into Arkansas. In this connection it should be stated that the oyster from the vicinity of Woodland, in Red River County, identified by Miss Alva C. Ellisor[1] as *Ostrea lugubris* Conrad, is not that species, but a form closely related to *Ostrea sannionis* White, which occurs in the Frontier sandstone of Wyoming. The Texas form occurs in a somewhat tuffaceous sandstone forming the upper part of the Woodbine formation in the vicinity of Woodland. Miss Ellisor's material consisted of prints of several very imperfect fragments. These she submitted to me, and I agreed with her at the time that they were more like *Ostrea lugubris* Conrad than any other species then known to me. I have since, however, collected perfect specimens of the oyster near Woodland.

The Eagle Ford appears to be represented in Arkansas by the unconformity separating the Woodbine sand (lower part of "Bingen") from the Tokio formation (upper part of "Bingen"). In central Texas, clay representing the Woodbine sand pinches out and disappears somewhere south of Belton, Bell County, but the overlying Eagle Ford extends on to the southward and southwestward, reaching the Rio Grande in Val Verde and Kinney counties. Where the Woodbine is absent the Eagle Ford rests unconformably on the Buda limestone, the uppermost division of the Comanche series.

There is evidence that from northeastern Texas southward at least to Hays County the Eagle Ford clay is separated from the overlying Austin chalk by an unconformity representing uplift and erosion. From Hays County to the Rio Grande, evidence of an unconformity is absent at this contact, and there is some reason to believe that in Kinney County the two formations are conformable. The unconformity where present probably represents a time interval of relatively short duration.

The Eagle Ford clay of central Texas, as in the vicinity of Austin and San Antonio, where it is only 30 or 40 feet thick, probably represents only the upper part of the formation as developed in northeastern Texas, where the thickness in places reaches 500 feet.

Buried coastward extension of the Eagle Ford.—The Eagle Ford clay extends for a long distance coastward beneath the Austin chalk and is penetrated by all the wells drilled along the Mexia-Powell fault zone, and the upper part of the formation appears in a small exposure in the Palestine salt dome 6 miles west by

[1] Alva C. Ellisor, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 9 (1925), p. 1164.

south of Palestine in Anderson County, where, according to Powers,[1] the Eagle Ford beds must have been lifted by the salt plug to a level fully 5,000 feet above their normal position.

Fossils of Eagle Ford age have been obtained from deep wells in DeSoto Parish, Louisiana, along the south flank of the Sabine uplift, a distance of 170 miles from the nearest outcrop of the formation in northeastern Texas.

AUSTIN CHALK AND ITS EQUIVALENTS

Character.—The Austin chalk is composed of chalk and chalky limestone, bluish gray where freshly exposed, but weathering to white, with interbedded layers of argillaceous chalk and calcareous shaly clay or marl.

Distribution and stratigraphic relations.—The Austin is one of the most extensively developed formations of the Gulf series in Texas, being equaled in its linear extent by the Eagle Ford clay only. Both the Austin and the Eagle Ford extend from northeastern Texas to the Rio Grande.

As has already been explained, the Austin rests unconformably on the Eagle Ford throughout most of its extent in northeastern and central Texas, but the two formations may be conformable in the Rio Grande region.

There is evidence of an unconformity between the Austin chalk and the overlying Taylor marl in Hill County and in Comal County, Texas, and the two formations probably are unconformable in the intervening area, a distance of at least 175 miles. From San Antonio westward, where the Anacacho limestone overlies the Austin, no evidence of an unconformity has been observed, and from Dallas northward the chalk seems to be conformable with the overlying Taylor. Northward from Dallas the top of the chalk appears to become successively younger and stratigraphically higher, until in the Greenville-Sherman section the topmost layer of the chalk, as, for example, in the vicinity of Leonard in Fannin County, may correspond in age to the middle part of the type Taylor marl in Williamson County. This interpretation is based on a study of the surface distribution of the chalk in Fannin, Grayson, and Collin counties and, if correct, the chalk in the Greenville-Sherman section should be thicker than it is at Dallas, perhaps attaining a maximum of 800 or 900 feet. From the Greenville-Sherman section eastward this thickened body of chalk is represented by a series of intertonguing chalky and non-chalky beds, which, in ascending order, are as follows:

a) The lowest division composes the basal part of the deposits of Austin age. In this area these basal beds consist of 10 to 35 feet of shaly clay and sand with the basal bed, the "fish bed conglomerate" of Taff, resting unconformably upon a sand bed at the top of the underlying Eagle Ford clay.

b) The next division is the Ector tongue of the Austin chalk, a tongue-like body of chalk, 50 feet or less in thickness, near the base of the main body of the

[1] Sidney Powers, "Interior Salt Domes of Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10 (1926), figures on pp. 47 and 53.

Austin in western Fannin County. It is traceable northeastward through Fannin County to a point a few miles northeast of Ravenna, where it probably thins out and disappears.

c) The Ector tongue is overlain by the Bonham clay, a partly calcareous and partly non-calcareous clay which toward the west, in Fannin County, merges into the Austin chalk, and toward the east extends through Fannin, Lamar, and Red River counties. In Lamar and Red River counties the lower part of the Bonham clay is decidedly marly, whereas the upper part is only slightly calcareous. The formation is named for small exposures a short distance north of the town of Bonham, Fannin County, Texas, and for the fact that the town, particularly the part north of the railroad, is located on the clay.

d) In east-central Fannin County and in Lamar and Red River counties the Bonham clay is overlain by the Blossom sand, which corresponds in age to the upper part of the typical Austin chalk at Austin. This sand appears to merge westward into the Bonham clay in Fannin County.

e) The Blossom sand is overlain by the Brownstown marl, a calcareous shaly clay or marl which ranges in thickness from 75 to 200 feet or more, and merges westward into the expanded body of the Austin chalk in the Greenville-Sherman section.

f) Above the Brownstown marl as herein restricted is a tongue of the Austin chalk formerly incorrectly correlated with the Annona chalk and in this paper designated the Gober tongue of the Austin chalk. Gober is a village in the south-central part of Fannin County, 7 miles south of Dodd City, and is situated on this chalk. The Gober tongue extends eastward from the upper part of the expanded body of the Austin chalk in the southwestern part of Fannin County. Where it connects with the main body of the chalk this tongue is probably not less than 400 feet thick, but it gradually thins out toward the east and appears to pinch out entirely in the eastern part of Lamar County. The thinning of the chalk of the Gober tongue toward the east may be due in part to mergence into, and intertonguing with, the Brownstown marl, for in the area between Honey Grove, Fannin County, and High, Lamar County, the lower part of the Gober is composed in part of soft more or less chalky clay or marl. The lowest layers of chalk, which are exposed in a cut about 1¼ miles west of High, are regarded as forming the base of the Gober tongue. This chalk is probably in the nature of a minor tongue which dies out toward the east. The uppermost bed of the Gober tongue, from the central part of Fannin County to the eastern part of Lamar County, is a soft tough limestone facies, 1–10 feet thick, which is suitable for building stone. Stratigraphic and paleontologic evidence seem to indicate that, although the Gober tongue is connected with the main body of the Austin, it is younger than the typical Austin chalk at Austin.

The typical Austin chalk, that is, the Austin as it is developed in the vicinity of Austin, is represented in Arkansas, at least in part, by the Tokio formation. The expanded part of the Austin in the Greenville-Sherman section is repre-

sented in part in Arkansas by the Brownstown marl as restricted by Dane,[1] that is, by the lower part of the Brownstown marl of Veatch.

Buried coastward extension of the Austin.—The Austin chalk extends many miles coastward from the outcrop beneath overlapping younger formations. It is recognizable in all the deep wells drilled along the Mexia-Powell fault zone, where it lies immediately above the Eagle Ford clay. The chalk brought up by the upthrust of the salt plug in the Palestine salt dome in Anderson County is probably Austin, as it lies in contact with the Eagle Ford and carries some fossils that suggest its Austin age. There is a possibility, however, of its being a chalk of Taylor age faulted against the Eagle Ford.

Toward the east and northeast in Texas the Austin chalk passes into clays and sands of non-chalky character, and chalk of the age of the typical Austin is probably wanting, both in outcrop and in the underground, in northeastern Texas east of Fannin County, in southwestern Arkansas, and in northwestern Louisiana. The chalks in the section overlying the Sabine uplift are believed to be of Taylor and lower Navarro age.

TAYLOR MARL AND ITS EQUIVALENTS

Character.—The Taylor marl is typically a shaly calcareous clay or marl, but the formation includes subordinate facies which range from almost non-calcareous clay to true chalk, and from slightly sandy clay to nearly pure fine sand. The formation attains a maximum thickness of 1,300 feet or more in McLennan County.

Distribution and stratigraphic relations.—The Taylor is fairly well developed as a clay marl from Red River County, Texas, in the northeast to the eastern part of Medina County, Texas, in the southwest. It rests with unconformable relations on the Austin chalk probably from Hill County to Comal County, a distance of 175 miles. It is represented in western Medina, Uvalde, and eastern Kinney counties by the Anacacho limestone, though in eastern Medina County and in western Bexar County the westward-thinning body of the Taylor marl overlaps the eastward-thinning tongue-like extension of the Anacacho. Still farther west, in Kinney and Maverick counties, the Anacacho is represented by the Upson clay and the San Miguel formation. No evidence of an unconformity has been observed between the Taylor marl and the underlying Austin chalk (including the Gober tongue) north of Ellis County in northeastern Texas. The lower part of the Taylor is believed to merge along the strike, perhaps by minor intertonguing, northward into the chalk which constitutes the thickened portion of the Austin chalk in Collin, Grayson, and Fannin counties. The Gober tongue of the Austin therefore is the time representative of the lower part of the type Taylor. The upper part of the Taylor is represented in part by the Wolfe City sand member of the Taylor marl and in part by the Pecan Gap tongue of the Annona chalk. In Red River County the Taylor marl proper merges eastward into the Annona chalk.

In central Texas the Taylor marl is believed to be unconformably overlain by

[1] *U. S. Geol. Survey Press Bulletin No. 8823*, July, 1926.

the Navarro formation, and farther west the Anacacho limestone, which represents the Taylor, is unconformably overlain by the Escondido formation. In Maverick County the San Miguel formation, which represents the upper part of the Taylor, is probably unconformably overlain by the so-called "coal series," which, on a subsequent page of this paper, is named Olmos formation. The evidence for the unconformity at the top of the Taylor and its western equivalents is found in the absence of the zone of *Exogyra cancellata* from Hill County to the Rio Grande, a distance of more than 300 miles. The relations are such that the only satisfactory explanation for the absence of this zone is the existence of an unconformity marking an erosion interval.

Beds of Taylor age in northeastern Texas.—The stratigraphic relationships of the chalks, sands, and marls of Taylor age in northeastern Texas have recently been the subject of considerable study by geologists of the Geological Survey and of several of the oil companies, and one important contribution has appeared in print.

In a paper read before this Association in March, 1925, and published the following November in the *Bulletin*,[1] Miss Ellisor correlated the Pecan Gap chalk with the Annona chalk of Red River County, Texas, and called particular attention to the error which I had made in correlating and mapping the Annona with the chalk which in the present paper is called the Gober tongue of the Austin chalk. At the time my paper on the geology of northeastern Texas was published (1918),[2] I had examined in a superficial way only the Annona chalk at Clarksville in Red River County and the chalk of the Gober tongue south of Paris in Lamar County, and I had done no field work whatever in the intervening area. Only small collections of imperfect fossils were made from the chalks, and no critical study was made of them. The principal reason for making the correlation at that time was that C. H. Gordon,[3] who had worked in the area, had mapped a band of chalk 3 to 6 miles wide, extending from the type area of the Annona chalk in Red River County continuously westward through Lamar County, connecting with the Gober chalk south of Paris. At that time there seemed no reason to doubt the accuracy of his mapping. However, a few days of field work in the area between Clarksville and Paris, in 1925, convinced me that the mapping was inaccurate.

The correlation of the Pecan Gap chalk with the Annona chalk is correct in part, but I am unable to agree that the Annona as a whole, as it is developed in Red River County, should be considered of Pecan Gap age, using that name in its original sense, that is, as applied to the Pecan Gap chalk in its type area. In the western part of Red River County and in Lamar, Delta, and Hunt counties the Pecan Gap chalk is in places scarcely more than 25 feet thick, and is probably nowhere more than 50 feet thick. Eastward, toward Clarksville, the chalk suddenly expands in thickness to 300, or possibly as much as 400, feet. It seems unlikely, almost incredible, that this greatly expanded body of chalk should be the time

[1] Alva C. Ellisor, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 9, No. 8 (1925), pp. 1152–64.

[2] L. W. Stephenson, *U. S. Geol. Survey Professional Paper 120* (1918), pp. 151–52, Plate 17.

[3] C. H. Gordon, *U. S. Geol. Survey Water Supply Paper 276*, Pl. 1, 1911.

equivalent of no more than the 25–50 feet of typical Pecan Gap chalk, and in my opinion the Annona chalk of Red River County is the age equivalent not only of the Pecan Gap chalk, but of the underlying Wolfe City sand member of the Taylor marl, and of most, if not all, of the still lower Taylor beds as they are developed in Lamar and Red River counties.

Miss Ellisor has examined samples from the upper part of the Annona in the immediate vicinity of Clarksville, and has correctly correlated that part of the Annona with the Pecan Gap chalk. It is in this part of the Annona that the large echinoid "*Ananchytes*," or *Echinocorys*, as it should properly be called, occurs as a characteristic fossil. She has also examined samples of chalk from White Rock, 7½ miles northeast of Clarksville, and correlates that chalk with the Pecan Gap. The chalk at White Rock is stratigraphically lower than the upper part of the Annona, from which it is separated by a band of chalky clay, or marl, which can hardly be called a true chalk. The explanation for the presence in the lower chalk of a micro-fauna resembling that of the true Pecan Gap is to be found, I think, in a similarity of environmental conditions, rather than in exact correspondence in age. In other words, within the limits of the time required for the deposition of a formation such as the Taylor marl and its equivalents, the recurrence of a given set of environmental conditions may result in the recurrence and preservation of a similar, though probably not identical, assemblage of micro-organisms. The purer chalk in the lower part of the Annona at White Rock is very much like the purer chalk in the upper part of the Annona at Clarksville, and it is therefore not surprising—and, indeed, rather to be expected—that the chalk at White Rock should contain a micro-fauna resembling that of the Pecan Gap chalk.

Equivalents of the Taylor marl in Arkansas.—The representatives of the typical Taylor marl in Arkansas are, in ascending order, the Brownstown marl, restricted (lower part of the Brownstown of Veatch), the Ozan formation of Dane[1] (upper part of the Brownstown of Veatch), and the Annona chalk. Of these the Brownstown represents the lower part of the Taylor, and the Ozan and the Annona represent the upper part of the Taylor. The middle part of the Taylor is represented by the unconformity separating the Brownstown, restricted, from the overlying Ozan. The Marlbrook marl, restricted (that is, the typical marl below the Saratoga chalk), according to Dane, conformably overlies the Annona chalk; and although it appears to be wanting in the section in northeastern Texas, it is regarded as more closely related in age to the Taylor marl than it is to the Navarro formation.

Fossils collected by Dane and Stephenson show that the Marlbrook marl as restricted and redefined in this paper carries in its upper part a form of *Exogyra* closely related to the more typical *Exogyra ponderosa* Roemer of lower horizons, but showing a transitional variation between that species and *Exogyra cancellata* Stephenson. Fairly typical specimens of *Exogyra cancellata* Stephenson are also present in association with the transitional forms, but the really typically representatives of the species occur in the lower part of the overlying Saratoga chalk. The

[1] C. H. Dane, *U. S. Geol. Survey Press Bull. No. 8823*, July, 1926.

species is absent in the upper part of the Saratoga and is not present at any higher horizon. Dane's careful work in the area seems to show that *Exogyra costata* Say is absent from the Marlbrook, restricted, but it is well represented in the Saratoga, the base of which appears to mark the base of the *Exogyra costata* zone proper. Because of the absence of *Exogyra costata* Say from the Marlbrook and the conformable relation of that formation to the underlying Annona chalk, the Marlbrook should probably be regarded as forming the upper part of the zone of *Exogyra ponderosa* Roemer, and as faunally more nearly related to the upper part of the type Taylor than to the lower part of the Navarro.

Miss Ellisor's determinations of micro-faunas in Arkansas afford other examples of the recurrence of faunas, for there similar assemblages of *Foraminifera* are found in equivalents of both the Taylor marl and the Navarro formation. At Rocky Comfort, Little River County, Arkansas, there is exposed a chalk which Miss Ellisor correctly regards as of Pecan Gap age, that is, upper Annona. At White Hill, or Bayou Hill, 2.9 miles southwest of Rocky Comfort, is another exposure of chalk which she says "contains a micro-fauna similar to that of the Saratoga chalk." Dane and Stephenson examined the chalk at White Hill in April, 1926, and we agree that on the basis of lithologic similarity, similarity in the succession of individual beds, and stratigraphic position with reference to the chalk at Rocky Comfort, the chalk at White Hill is upper Annona and not Saratoga; we also found in the chalk several specimens of the large echinoid *Echinocorys*, which characterizes the upper Annona and has never been found as high as the Saratoga. The Saratoga chalk generally contains an abundance of the larger fossils, some of them characteristic and never found as low as the Annona, and these were absent at White Hill. Apparently there is in the Annona chalk at White Hill a micro-fauna resembling a fauna which later recurs under somewhat similar environmental conditions in the definitely younger Saratoga chalk.

Miss Ellisor has identified micro-faunas from sands in the Ozan formation at several localities in Arkansas, and she states that the association of *Foraminifera* in these sands is the same as in the Wolfe City sand of Texas. Dane has determined that in Sevier and Little River counties, Arkansas, the Ozan contains two well-developed sands separated by 70 feet or more of shaly clay. One of the occurrences of the so-called "Wolfe City micro-fauna" is half a mile south of Brownstown, in Sevier County, and this is the lower of the two sands. Another locality is on the Arkinda road, 3½ miles northwest of Foreman, Little River County, and this is the upper of the two sands. This is another example of the recurrence of faunas in consequence of the recurrence of similar environmental conditions. I am inclined to believe that both of these sands are stratigraphically a little lower than the Wolfe City sand.

A chalk exposed in the vicinity of Okolona, Clark County, Arkansas, is correlated by Miss Ellisor with the Pecan Gap chalk, that is, upper Annona. This chalk contains a fauna of echinoids and mollusks that proves conclusively its Saratoga age.

These citations are not intended as a destructive criticism of the science of micro-paleontology as applied to stratigraphy, nor as a discouragement to those investigators who, like the author of the paper cited, have so persistently, and in many respects so successfully, endeavored to make the science a valuable means of correlation where other criteria have failed. The citations do, however, show the need of more critical study of specific and varietal differences between micro-organisms of different faunal assemblages which bear a general resemblance to each other. With a continued and more critical study of the significance of micro-faunal assemblages and the more critical discrimination of the specific and varietal characters of micro-organisms, and with due regard to the stratigraphic relationships which may often be determined by field observations with or without the aid of the larger fossils, the science of micro-paleontology will doubtless be developed to a stage of great usefulness, especially in the interpretation of well data.

Buried coastward extension of the Taylor.—The Taylor marl extends coastward for many miles beneath younger Cretaceous and Tertiary formations and has been penetrated by many wells. That the marl extends at least as far east as Anderson and Smith counties, a distance of 45 to 50 miles from the nearest normal outcrops of the formation, is shown by marl identified as belonging to the Taylor, which has been brought to the surface around Keechi and Brooks salt domes.

NAVARRO AND ESCONDIDO FORMATIONS

Character.—The Navarro formation is the uppermost division of the Gulf series, extending from northeastern Texas to the vicinity of San Antonio, in Bexar County. It consists of shaly clay, calcareous shaly clay or marl, sandy clay, and marine sand more or less calcareous and glauconitic. The sandy beds occur chiefly near the middle of the formation, where they approximately represent the westward and southwestward extension of the Nacatoch sand of Arkansas. Some of the sandy beds are cemented into sandstone by calcium carbonate.

The Escondido formation, which approximately represents the Navarro formation from Medina River westward, consists of shaly clay, finely sandy clay, and medium to fine argillaceous sand, interbedded with subordinate irregularly bedded sandstone.

Stratigraphic relations.—In the northeast the Navarro formation is underlain by the Annona chalk in Red River County and by the Pecan Gap tongue of the Annona chalk from Red River County as far south as Kaufman County. Although the contact has not been seen clearly exposed, the apparent absence in northern Texas of beds representing the restricted Marlbrook marl suggests that in Texas the Navarro rests unconformably on the Annona chalk and on the Pecan Gap tongue of the Annona. Further study is needed to confirm this interpretation. The narrowing of the belt of outcrop of the Navarro formation from Navarro County southward suggests the continuation of a stratigraphic break between the Navarro and the underlying Taylor in that direction, and from Falls County to Bexar County, a distance of 150 miles or more, the total absence of the zone of

Exogyra cancellata, which in northeastern Texas forms the lower part of the Navarro, is evidence of a pronounced unconformity at the base of that formation.

The relationship of the Navarro formation to the Escondido formation has never been precisely determined, but in a general way the one is the approximate equivalent of the other. It appears that a westward-thinning wedge of Navarro-like materials pinches out beneath an overlapping, eastward-thinning wedge of Escondido-like materials in the western part of Bexar County and the eastern part of Medina County.

Fossils near the base of the Navarro formation in Bexar and Medina counties and near the base of the Escondido formation farther west in Medina County indicate that these basal beds correspond in age to about the middle of the Navarro as that formation is developed in northeastern Texas. This indicates the existence of an important unconformity at the base of both the Navarro and Escondido formations in the Bexar-Medina County area. The unconformity between the Taylor and Navarro formations is continued westward between the Anacacho limestone and the overlying Escondido formation, but in Maverick County the stratigraphic gap represented by the unconformity is partly filled by the non-marine beds heretofore known as the "coal series," and here named the Olmos formation, which intervene between the San Miguel and Escondido formations.

The name Olmos is derived from the flag station of Olmos, located on the outcrop of the formation, and from Olmos Creek (now generally called by its English equivalent, Elm Creek), which follows the strike of the formation near the center of the belt of outcrop from a point 7 or 8 miles north of Eagle Pass to the junction of the creek with the Rio Grande. The thickness of the Olmos formation ranges from a feather edge to 400 or 450 feet. The formation consists of greenish-gray shaly clay and finely sandy clay, irregularly interbedded with fine to coarse, greenish-gray, thin-bedded to massive, more or less cross-bedded soft to hard sandstone, some layers of which are ripple-marked, and with seams of coal and lignite. There is probably an unconformity at both the base and top of the Olmos formation.

The upper part of the Escondido formation is probably somewhat younger than the uppermost beds of the Navarro formation in central and northeastern Texas, but that these younger beds were formed well within the limits of the Mesozoic era is attested by their ammonite fauna (several species of *Sphenodiscus*), and they cannot be regarded as filling any considerable part of the great stratigraphic gap which separates the Cretaceous from the Eocene in the Texas coastal plain.

The Navarro formation of central and northeastern Texas and the Escondido formation of the southwestern part of the State are separated from the overlying Midway formation (Eocene) by a regional unconformity representing a relatively long interval of geologic time. The great length of time represented by this unconformity is indicated by the striking differences in the character of the fossil organisms found in the beds below and above the contact. For example, not a single molluscan species is known with certainty to be common to the uppermost Cretaceous beds and the beds of the overlying Midway formation (Eocene). Although many Cretaceous molluscan genera are represented in the Midway by new

species, descendants of the earlier Cretaceous species, a long list of genera that became extinct at the end of the Cretaceous may also be enumerated, among which may be mentioned all the many genera of one whole order, the *Ammonoidea*. Similar striking faunal differences exist between the representatives of other groups of organisms below and above the Cretaceous-Midway contact, as, for example, the *Protozoa* (particularly the foraminifers), the *Coelenterata* (particularly the corals), and the *Echinodermata* (particularly the echinoids).

Scott[1] has recently questioned the time importance of the Cretaceous-Midway unconformity, chiefly on the basis of one European species which he incorrectly identifies with an American species, but his statement will hardly be given serious consideration by anyone who has made a critical comparison of the faunas below and above the contact.[2]

Arkansas equivalents.—The strata in southwestern Arkansas which correspond in age to the Navarro formation have been divided, in ascending order, into the Saratoga chalk, the Nacatoch sand, and the Arkadelphia marl.

The Saratoga chalk has heretofore been defined as forming the upper member of the Marlbrook marl, and the Marlbrook, including the Saratoga, has been correlated with the lower part of the Navarro formation. As stated elsewhere in this paper, the recent studies of Dane indicate that the Marlbrook marl as restricted conformably overlies the Annona chalk and is unconformably overlain by the Saratoga chalk, so that it is now evident that the Saratoga should no longer be classed as a member of the Marlbrook, and that the latter name should be restricted in its application to the marl proper below the chalk. The Marlbrook is more closely related in age to the Taylor than it is to the Navarro.

Buried coastward extension of the Navarro.—The Navarro, like the older formations of the Gulf series, extends far eastward beneath the younger Tertiary formations and has been definitely recognized in outcrops around Keechi salt dome in Anderson County, a distance of 30 miles east of the main outcrop of the formation. The fossil evidence indicates that the lower Navarro or *Exogyra cancellata* zone, and beds belonging to the middle or upper Navarro, or both, are represented in these outcrops.

UNCONFORMITIES

The formations composing the Gulf series do not record continuous sedimentation throughout Gulf time. The several major unconformities already described and other minor unconformities mark interruptions to sedimentation, which resulted either from emergence and erosion or from a shallowing of the sea such that the waves and currents prevented the accumulation of sediments.

The unconformity which separates the Gulf series from the underlying Comanche series is traceable from the Rio Grande in the southwest to Red River in the

[1] Gayle Scott, "On a New Correlation of the Texas Cretaceous," *Amer. Jour. of Science*, Vol. 12 (1926), pp. 157–61.

[2] While this paper was in press a note criticizing Scott's interpretation of the Cretaceous-Eocene contact in Texas, by Dr. Julia Gardner, appeared in the *American Journal of Science*, Vol. 12, pp. 453–55, 1926.

northeast, and thence on eastward into Arkansas. This unconformity marks a period of uplift and erosion between the time of deposition of the Comanche series and that of the Gulf series. Land conditions prevailed from the Rio Grande to southwestern Arkansas, and evidently the greatest amount of erosion was effected in Arkansas, where the Woodbine formation rests upon the Trinity, the lowermost division of the Comanche series.

The accumulation of the Gulf series began with submergence in northeastern Texas and southwestern Arkansas, as recorded in the sediments of the Woodbine formation, and was continued, perhaps after a brief period of emergence and erosion with somewhat deeper submergence, by the deposition of the marine clay which composes the overlying Eagle Ford formation. The Eagle Ford sea spread almost across Texas, from Lamar County in the northeast to the Rio Grande.

An important unconformity separates the Eagle Ford clay from the overlying Austin chalk, at least from Lamar County in the northeast to Hays County in the southwest, and perhaps even farther toward the Rio Grande. This unconformity marks another period of uplift and erosion of wide extent which was brought to a close by submergence and the deposition of the Austin chalk and its equivalents.

The next extensive stratigraphic break is at the contact between the Austin chalk and the overlying Taylor marl, and probably extends from Hill County to Comal County, Texas, a distance not less than 175 miles. The emergence recorded by this unconformity did not affect as broad an area as either of the two preceding ones, but the uplift was of sufficient extent to place it in the category of an important diastrophic event.

On the basis chiefly of paleontologic evidence an unconformity is postulated between the Taylor marl (and beds of Taylor age) and the overlying Navarro formation and its equivalents from northeastern Texas southwestward to the Rio Grande, a distance of nearly 500 miles. Although the physical evidence for the unconformity is obscure at most places, the paleontologic evidence throughout a considerable part of the area seems to be conclusive. At many places between Milam County in central Texas and the Rio Grande beds carrying *Exogyra costata* Say, which exhibit strongly developed costae of medium width such as characterize the middle part of the Navarro formation (*Exogyra costata* zone), are found lying closely above beds belonging to the Taylor marl that carry typical *Exogyra ponderosa* Roemer. The *Exogyra cancellata* zone is absent. The relations are such that the only satisfactory explanation of the absence of the *Exogyra cancellata* zone is the existence of an unconformity marking an erosion interval between the Taylor and Navarro formations. The eastward continuation of this stratigraphic break is the unconformity which separates the Marlbrook marl from the overlying Saratoga chalk in Arkansas. In contrast to the conditions in Texas this contact is well exposed at many places in Arkansas, where it has the physical aspect of a true unconformity. The Marlbrook marl and its accompanying fauna seem to be absent in northeastern Texas, where the marl is represented by the unconformity separating the Annona chalk from the Navarro formation.

Finally, there is at the top of the Gulf series an unconformity of regional extent throughout the Atlantic and Gulf Coastal Plain. In Texas this unconformity lies between the Navarro and Escondido formations of the Cretaceous on the one hand, and the Midway formation of the Eocene on the other. It is second in importance only to the unconformity which separates the sediments of the Coastal Plain from the underlying basement rocks. In Arkansas this unconformity lies between the Arkadelphia marl and the Midway formation.

In addition to these major unconformities there are minor sedimentary breaks of local extent, most of which are indicated by more or less sandy and calcareous layers carrying phosphatic molds of fossils, phosphatic nodules, and glauconite. We do not know as yet the criteria for properly evaluating these phosphatic layers, but they occur both at contacts representing important time breaks and at those which mark local and unimportant time breaks. Some of the phosphatic layers are sharply separated from the underlying strata whose bedding planes are truncated by the line of contact; these would seem to mark true unconformities. Not uncommonly the borings of some as yet unidentified marine organisms extend from the contact into the underlying stratum to maximum depths of 18 inches, and have been filled with material identical with that composing the phosphatic layer. It is conceivable that a contact of this kind might be produced in a shallow sea without emergence and erosion. But, as Goldman[1] has pointed out, these phosphatic layers probably indicate interruptions to the continuity of sedimentation, whether caused by a mere shallowing of the sea or by actual emergence and erosion. There is evidence for the existence of several unconformities in the Gulf series in northeastern Texas and southwestern Arkansas, and these doubtless account in large part for the great thinning of the Gulf series in that area. Many more unconformities of greater or less importance will probably be discovered in the Gulf series as more intensive studies are carried on in the future.

These unconformities furnish an interesting record of diastrophic movements involving uplift and depression, and differential warping along the zone of outcrop of the Gulf series and a consequent succession of advances and retreats of the sea from time to time during the Upper Cretaceous period.

ZONES OF EQUAL AGE

In the diagram (Plate 1) an attempt is made to connect zones of approximately equal age in the different columns by the use of heavy numbered lines. The divergence of these lines in the Greenville-Sherman-Dallas region and in the Rio Grande region represents a thickening of the Gulf series in those areas. The converging of the lines in the Austin region and in northeastern Texas and southwestern Arkansas represents a thinning of the series in those areas. The thinning is probably due in part to actual thinning of formations, but in the main it is due to unconformities within the series.

[1] Marcus I. Goldman, "Basal Glauconite and Phosphate Beds," *Science*, N.S., Vol. 56 (1922), p. 171.

THE NORTHERN CORDILLERAN GEOSYNCLINE AND ITS RELATION TO PETROLEUM ACCUMULATION[1]

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ABSTRACT

Attention is directed to the petroleum possibilities of the great province that lies between Hudson Bay and the Canadian Rockies. A general review of the sedimentation and earth's movements within this geosyncline of 300,000 square miles, from Cambrian time to the present, indicates that the major features compare favorably with other geosynclines which have yielded large amounts of petroleum. Geologists have already outlined, in a general way, some of the probable petroleum areas, and development has centered about ten localities. The results so far obtained, together with the general favorable conditions and numerous oil seepages, constitute evidence which cannot be ignored by oil companies desiring new producing territory. Systematic geological work has but scarcely begun in the Canadian Great Plains, which are believed to comprise the largest remaining undeveloped area having oil possibilities on the North American continent. A thorough systematic exploration of the region is merited.

INTRODUCTION

The writers, in the preparation of this paper, have attempted to do little more than briefly review the more salient features of the geology and oil possibilities of that vast and little known region lying between the Laurentian Highlands surrounding the Hudson Bay, and the front range of the Canadian Rockies, known as the Canadian Great Plains region. Although *reconnaissance* geologic studies, especially along Mackenzie River and in widely scattered areas adjacent thereto, have been made by Dominion geologists at different times, it has only been within the last ten years that systematic exploration of the geology of that extensive region, having in mind its bearing on oil accumulation, has been carried on.

It is not the purpose of this paper to give details of an area of such vast extent, but rather to deal in generalities, pointing out some of the broader geologic and physical features which, in the light of experience gained in the development of the petroleum resources of the United States, are believed to be worthy of systematic exploration.

As the writers' observations in this region have been confined to the southern half of Alberta and Saskatchewan and parts of British Columbia, all the information concerning the area north of Latitude 54, as well as some concerning that to the south, has been drawn from reports by geologists of the Canadian Government and other workers in this field.[2] Much is yet to be learned about this area, which

[1] Read before the Association at the Denver Meeting, September, 1926. Manuscript received by the editor, October 10, 1926.

[2] The information is obtained from many sources, and specific references are made only to a few. No attempt has been made to compile a bibliography of the region.

is 1,500 miles long and from 200 to 800 miles wide, comprising over 300,000 square miles of territory lying between the Rocky Mountains on the west and the Laurentian Highlands on the east. The region offers a broad field for petroleum exploration.

FIG. 1

The Great Plains of Canada are bounded on the west by the Rocky Mountains, extending from the international boundary northwestward to the vicinity of Liard River, where they are broken up into several low ranges. North of Liard River the Mackenzie Mountains, lying about 150 miles east of the Rocky Mountain range and approximately parallel to it, form the boundary of the Plains region northward to about Latitude 66° N., where they swing sharply to an east-west

trend. South of the Mackenzie Delta, Peel River drains an extensive basin which is a part of the Plains area. A little farther west, however, along the international boundary, the mountains extend practically to the Arctic Ocean. Eastward the Plains region extends to the edge of the broad area of pre-Cambrian rocks forming the Canadian Shield, the division line running in a nearly straight course from Lake Winnipeg northwestward through Athabaska Lake and Great Slave Lake to Great Bear Lake, thence northward to the Arctic Ocean.

The present site of the northern Rocky Mountain system has long been recognized as an area of extensive deposition, especially during Paleozoic times, and paleogeographic maps by different authors have shown, at recurrent periods, long, generally narrow seaways extending roughly along the present axis of the Rocky Mountains. The development of this great geosynclinal area was periodic: periods of rapid deposition in sinking basins alternating with periods of slow deposition in broad, shallow seas and with periods of emergence. The more salient features of this geosynclinal area are described by Schuchert in his presidential address to the Geological Society of America in 1922. The following quotation is taken from his paper.[1]

The longest and widest, and by far the oldest and longest-continuing seaway is the one long known as the Cordilleran geosyncline. During the Paleozoic it extended from the Arctic Ocean southward through what is now the mountainous region of western North America into northwestern Mexico, a distance of 3,000 miles. In Canada the width of the seaway is usually several hundred miles, while in the United States it is many hundreds of miles wide, and at times attains a breadth of more than 1,000 miles. The eastern shores of this vast geosyncline and its marine extensions are the Canadian Shield, and its southern prolongation, Siouia, while its oceanward borderland is Cascadia, to the west of which is the Pacific Ocean.

With the close of the Devonian, the Cordilleran seas begin to restrict, and their eastern shores, in the far north, begin to move westward. This change is further accentuated in the late Pennsylvanian and Triassic, so that by the end of Jurassic time there had arisen, almost out of the very center and along the entire length of this geosyncline, the very extensive Cordilleran intermontane geanticline. In Cretaceous times, then, there lay on the western side of this geanticline the Pacific geosyncline with a length of at least 2,500 miles, and on its eastern one, the Rocky Mountain geosyncline, or Coloradoan sea, extending in the form of a sigmoid curve from Behring Straits into the Caribbean Mediterranean, a distance of over 5,000 miles.

Just when the Cordilleran geosyncline came into existence is not known, but it is certain that its central part was present early in Proterozoic time, and seemingly with about the same position and extent as in the early Paleozoic. Its presence is clearly evidenced by the vast deposits of Proterozoic time in the Beltian series, extending from Great Salt Lake into British Columbia, to about 55 degrees north latitude. . . . . Probably the most extraordinary fact in our present studies is that of the conformable relations of the

[1] Charles Schuchert, "Sites and Nature of the North American Geosynclines," *Bull. Geol. Soc. Amer.*, Vol. 34 (1923), pp. 184–86.

Proterozoic and Paleozoic strata. In other words, there was no marked orogeny in the Cordilleran geosyncline at the close of the Proterozoic, as there clearly was in all the other marginal areas of North America.

The thicknesses of the Paleozoic formations throughout the western part of the Cordilleran geosyncline vary between 10,000 and 23,000 feet, being apparently greatest in the southern half. The Cambrian, Ozarkian, and early Ordovician deposits are very thick throughout the geosyncline, varying between 6,000 and 16,000 feet. It is the grandest known Cambrian sequence anywhere in the world, and our knowledge of it is almost wholly due to Walcott.

It is interesting to observe that most, if not all, of the great periods of the earth's history, from the Cambrian to the Cretaceous, are represented in the Canadian Rockies by sedimentary rocks of marine origin. In striking contrast to this only the Ordovician, Silurian, Devonian, and Cretaceous are represented in the eastern part of the Plains area.

The deposits of the Ordovician, Silurian, and Devonian periods in the Cordilleran and Plains regions of Canada were laid down under conditions markedly different from those of the Cambrian and pre-Cambrian. In the earlier periods great thicknesses of clastic materials were deposited in the Rocky Mountain trough, showing the presence of a mountainous area not far distant to the west, but the deposits of the later periods indicate widespread, shallow seas extending over the Rocky Mountain area, parts of the Plains area, and probably also a considerable distance westward.

ORDOVICIAN DEPOSITS AND EXTENT

Schuchert's paleogeographic map of the Ordovician[1] shows a broad sea extending from the Arctic Ocean over the greater part of the Canadian Shield, the Plains area, and the Rocky Mountain area of Canada, and extending also a short distance south in Montana and North Dakota. It shows, however, a large island in the region of Great Slave and Athabaska lakes. More recent investigation indicates that this area of emergence was much larger than is shown. In fact, there is little evidence that the Ordovician underlies much of the area north of the Lake Winnipeg district, where about 500 feet of limestone and shaly sandstone of Ordovician age are described. In the Franklin Mountains a red-bed series is tentatively assigned to the Ordovician, but the correlation is doubtful. The Ordovician is absent in the Great Slave and Athabaska lake districts.

Along the line of the Canadian Pacific Railway in the Rocky Mountains the Ordovician is not definitely recognized in the Front Range, but in the Beaverfoot range a 1,500-foot zone is reported, composed predominantly of black shale carrying a graptolite fauna. A similar graptolite shale series is reported on Dease River at about Latitude 60° N., and a graptolite shale series has been found in Kuskokwim River in the Mount McKinley region, Alaska. On Porcupine River and on Seward Peninsula, the Ordovician is represented by limestones.

[1] *Op. cit.*, p. 218.

There is little to indicate that the Ordovician is promising for oil production anywhere in the Canadian Plains region. A black shale series is always attractive, but it is doubtful if the graptolite black shales anywhere extend east of the mountains.

SILURIAN DEPOSITS AND EXTENT

Seas of Silurian age had a much more widespread distribution over the Canadian Cordilleran and Plains regions than did those of Ordovician age. In northwest Manitoba, northwest of Lake Winnipeg, the Silurian series consists of a few hundred feet of thin-bedded limestone of Niagaran age, with impressions of salt crystals and some gypsum. On Slave River and Great Slave Lake the Fitzgerald dolomite is underlain by a red-bed series containing salt and gypsum and forming the salt plains west of Slave River. This is believed to be Upper Silurian in age, the Middle and Lower Silurian being absent. West of the Great Bear Lake, however, in the Franklin Mountains, the Lower, Middle, and Upper Silurian have been recognized in a series of limestones and dolomites about 3,000 feet thick. Gypsum is found in association with the Upper Silurian limestone. Still farther northwest in the Fort Norman region the Upper Silurian only is recognized, but the association of limestone and dolomite with red shale and gypsum is still present.

In the Rocky Mountain area 1,300 feet of dolomites and quartzites in the second range of mountains along the line of the Canadian Pacific Railway and a similar series in Peace River pass are referred to the Silurian. On Porcupine River a series of dolomites and limestones of Silurian age is estimated to be about 2,500 feet thick. Above this are black shales interbedded with limestones containing a graptolite fauna.

The association of dolomite and limestone with red shales, gypsum, and salt over a great part of the Plains region suggests a possible similarity to conditions in the Permian of eastern New Mexico and western Texas. Van der Gracht has shown us that semi-isolated seas, with a tendency to supersaturation, may offer conditions exceptionally favorable for the origin of petroleum. Therefore the Silurian of the Mackenzie basin and even of Manitoba and Saskatchewan may be looked upon as potentially favorable for oil. So far as the writers know, however, no evidences of petroleum have yet been found in these beds.

DEVONIAN DEPOSITS AND EXTENT

The Middle and Upper Devonian seas were widespread in all the northern Cordilleran and Plains regions, and Devonian limestones and shales crop out extensively throughout the Mackenzie River basin. The Lower Devonian is not recognized anywhere in the Plains region and it is apparent that after the retreat of the Silurian sea, the area was above sea-level until Middle Devonian. The Middle Devonian is represented by limestones and dolomites in all of the Plains region.

In the Lake Winnipeg district the whole series is about 400 feet thick and may be all Middle Devonian. On Great Slave Lake the Middle Devonian is composed of two limestone groups separated by a dolomite series, the whole aggregating

nearly 1,200 feet in thickness. The middle Presqu'ile dolomite series is of special interest because at Nintsi Point and other places it is highly impregnated with oil and gives rise to several tar pools. It is described as coarsely crystalline and very porous. The Middle Devonian limestone of the Franklin Mountains is 2,000 feef thick, but in the Fort Norman area a thickness of only 700 feet is reported.

The Upper Devonian of the Great Slave Lake area is composed of about 650 feet of greenish-gray and dark shales overlain by 300 feet of limestone. In the Franklin Mountains the shale series—Simpson shale—is 1,000 feet thick, and in the Fort Norman area the corresponding Fort Creek shale is more than 1,500 feet thick and is overlain by a group of sandstones and shales 1,600 feet thick. Seepages of oil occur in the sandstones, and the discovery well in the Fort Norman field was drilled on one of these seepages, obtaining its oil probably from a sandstone member in the Fort Creek shales.

In the Front Range of the Rockies, along the line of the Canadian Pacific Ratlway, the Devonian is represented by 1,500 feet of brownish, dolomitic limestones with some sandstone and quartzite. On Porcupine River, Kindle recognized a lower limestone 325 feet thick, overlain by several hundred feet of brown shale, and in the Ogilvie Range, Latitude 64° 30′ N., Longitude 135° W., a thick series of limestones, quartzites, conglomerates, and black slates has been classified as Devonian. On Peel River the series consists of closely folded black slates and limestones, with the slates, in places, bituminous.

The dark gray and black shales of the Upper Devonian, as well as the underlying limestones and dolomites of the Middle Devonian, appear to offer a very promising source for oil. They are very widespread throughout the Mackenzie River basin, but probably the black shales disappear to the south, somewhere about the latitude of Athabaska Lake.

MISSISSIPPIAN TO TRIASSIC

In the Mackenzie valley and around the eastern border of the Great Plains area, the Devonian is overlain by rocks of Cretaceous age. In the mountains to the west, however, the Mississippian, Pennsylvanian, Triassic, Jurassic, and possibly the Permian are present and extend eastward under the Cretaceous basin south of Liard River.

In the Front Range along the line of the Canadian Pacific Railway the Banff series of Carboniferous age has a thickness of nearly 5,000 feet, and, according to G. A. Young,[1] "consists of a lower argillaceous member, a middle limestone member, and an upper sandy member":

> The whole succession is conformable, but sudden changes in the character of the fossil faunas indicate temporary withdrawals of the sea. The upper sandstone, or quartzitic horizon, appears to occur as far south as the International Boundary, and presumably this persistent horizon, with the underlying limestones, extends northward through

[1] G. A. Young, "Geology and Economic Minerals of Canada," *Geological Survey of Canada, Econ. Geol., Series No. 1* (1926), pp. 151–52.

the whole length of the Rocky Mountains and on into the Mackenzie Mountains. The measures disappear eastward beneath the Cretaceous beds of the Plains. To the north, a land area appears to have been present which separated the southern Carboniferous seas from an Arctic basin in which were deposited Carboniferous sediments that carry faunas unlike those found in the south and resembling the faunas of contemporaneous beds in the Arctic archipelago. The Carboniferous beds of the northern basin have been recognized in the vicinity of the Alaska boundary, both far north and south of the Yukon River. The measures north of the river, in places, have yielded faunas of Mississippian and Pennsylvanian age. The rocks are partly limestone, shale, and sandstones. The higher beds, largely of clastic types, may be of Permian age.

The rocks of Carboniferous age probably extend over a great part of the southern Plains region of Alberta and Saskatchewan.

Another marine invasion of the Rocky Mountain region took place in Triassic times, but was confined to a narrow trough and probably did not extend east of the present Rocky Mountain front. G. A. Young's[1] description of the Triassic of the mountain area is as follows:

In the Banff district, in the Rocky Mountain region, the Carboniferous beds are overlain, without angular conformity, by about 1,500 feet of sandstone and shale of marine origin and Triassic age. Beds of this age may extend throughout the length of the Rocky Mountains. They have been recognized along Peace and Liard rivers and occur in the western ranges of the Mackenzie mountains. Strata of this age may possibly occur in the western Yukon district. In these various areas the Triassic beds, though deposited after an interval of emergence from the sea, are essentially conformable with the underlying Paleozoic strata.

The Jurassic sea was much more widespread in the northern Rockies and Plains region than the Triassic, and over the latter region was comparable in extent to the Mississippian. Schuchert's paleogeographic map of the early Upper Jurassic or Logan sea[2] shows the rise of the Cordilleran intermontane geanticline, extending in a long, mountain range through Nevada, western Idaho, eastern Washington, and eastern British Columbia. This mountain range separated what Schuchert has designated as the Rocky Mountain sequent geosyncline on the east from the Pacific sequent geosyncline on the west, and was persistent until the close of the Cretaceous, when the whole of the interior of the continent was elevated above sea-level. Descriptions of the Jurassic beds of the Canadian Rockies are meager. Young has summarized the situation as follows:

In the Rocky mountains, from the International Boundary northward to and beyond Bow River Valley, the marine Triassic beds or, where these are absent, late Paleozoic strata, are succeeded by the dark marine shales of the Fernie formation of Jurassic age. The Fernie beds, in places, rest conformably on the underlying strata, but the presence, in places, of a few feet of basal conglomerate holding fragments of Paleozoic strata indicates that preceding Fernie time considerable areas lay above the sea and were subjected

[1] *Op. cit.*, p. 153.

[2] Schuchert, *op. cit.*, p. 226.

to erosion. The Fernie measures in the eastern ranges of the Rocky mountains are less than 1,000 feet thick, but near the International Boundary increase in thickness to the west where, in places, they are more than 3,000 feet thick.[1]

As Jurassic marine strata are well developed in Montana and in the Black Hills region the writers assume, as Schuchert has done, that they underlie a large part of the southern Great Plains area of Canada. The presence of oil in the Kevin-Sunburst field and the general character of the Fernie shale indicate that the Jurassic may be a very important source for oil in southern Alberta and possibly Saskatchewan.

CRETACEOUS DEPOSITS AND EXTENT

At present the Cretaceous strata, especially the lower part of the Upper Cretaceous, appear to be among the most promising sources for oil in Canada, both because of their general similarity to the Cretaceous of the Rocky Mountain region in the United States and because of the oil and gas fields that have already been developed in these beds.

The Lower Cretaceous is represented by the Kootenai formation which, at least in Alberta, is a non-marine formation composed of alternating, cross-bedded sandstones, dark shales, and thick coal beds. The formation decreases in thickness from west to east. The greatest thickness is about 5,000 feet.

With the advent of the Upper Cretaceous occurred the most widespread marine invasion in the history of the North American continent. Throughout the Great Plains area, extending from the Arctic Ocean to the Gulf of Mexico, occurs a thick series of dark shales which over wide areas are known to be important source rocks for oil. These are the Mancos, Benton, Niobrara, and Colorado shales in the United States. In parts of Alberta local names have been used, but the general conditions were uniform, probably all the way to the Arctic Ocean. Sandstones underlying, and interbedded in, the great shale series have proved by far the most important reservoirs of oil in the Rocky Mountain states and in Alberta. Compared with the United States, the possibilities in Alberta have been only superficially explored.

During Pierre or Montanan time, Alberta, like Montana and other Rocky Mountain states, had successive invasions and retreats of the sea. The principal periods of advancing seas were represented by shales corresponding to the Clagget and Bearpaw, and the periods of retreat were represented by thick, non-marine sandstones and shales corresponding to the Eagle, Judith River, and Lance. Along the foothills of the Rockies the sediments are composed predominantly of thick, non-marine clastics, but under the eastern Plains they are almost entirely uniform marine shale series (Pierre) from top to bottom.

DEVELOPMENT

Petroleum was first discovered in the province of Alberta in 1898, southwest of Pincher Creek, within the Front Range of the Rocky Mountains, although seepages of oil and gas were known throughout Alberta and the lower Mackenzie River

[1] Young, *op. cit.*, p. 155.

basin. Little interest was manifested in this discovery until 1914, when oil of high grade was discovered in the Dingham well, located in the Turner Valley southwest of Calgary. A boom followed this discovery and many companies were organized for exploration. Few of these companies, however, outlived their organization period. The world war retarded the search for oil in Canada from 1914 to 1919. During the latter year a systematic search was again taken up by large petroleum operators, corporations, and government departments. In 1920 and the years following, geologic field parties made surveys of different districts extending from the international boundary line to the area below Fort Norman on Mackenzie River. As a result of these and previous explorations, the present probable petroleum areas have been outlined in a general way by Canadian geologists.[1] Of course, further study will doubtless add many localities that will prove worthy of thorough testing. The areas which have received greatest attention are: (1) Southwestern Alberta, including Cardston, Pincher Creek, and Waterton Lakes districts. (2) Southeastern Alberta, along the margin of the Sweet Grass Hills, including Medicine Hat and Bow Island. (3) Okotoks field, including Sheep River and the Highwood and Willow Creek areas along the outer edge of the foothills. This group includes Turner Valley, which is a small producing field. (4) Central eastern field, including the Monitor, Czar, Viking, and Birch Lake areas. (5) Central western field, within the foothills between North Saskatchewan and Athabaska rivers. (6) Peace River field, in the vicinity of the town of Peace River and about 20 miles downstream within the limits of the valley. (7) Upper Peace River field, south of the river in the Peace River block, about Pouce Coupe and in the adjoining territory in Alberta. (8) Althabaska field, north and south of McMurray within a radius of about 60 miles. (9) Great Slave Lake field, the western end of the lake, including Windy Point area on the north and Pine Point area on the south. (10) Fort Norman field on the lower Mackenzie west of Great Bear Lake.

OIL INDICATIONS BY DISTRICTS

The surface indications of the presence of petroleum in the Canadian Great Plains are ample and compare most favorably with those which existed in the Rocky Mountain and Mid-Continent fields prior to their development. The frequent occurrences of oil seeps associated with local structural conditions along the Canadian foothills, the already developed commercial gas fields of the Sweet Grass Hills region, the unparalleled extent of the Athabaska tar sands in the vicinity of Fort McMurray, the limestones impregnated with bituminous matter in the Peace River and Great Slave Lake regions, and the development of the Fort Norman district are facts with which oil men and geologists are already familiar. Certainly evidence of this character cannot be passed over and treated lightly by oil companies endeavoring to open up new oil producing territory.

In earlier days the formations below the top of the "Mississippi lime" of the Mid-Continent fields and the oil-bearing sands below the Frontier formations in

[1] *Summary Reports, Geol. Survey Canada*, 1920–24.

the Rocky Mountain region were regarded as unworthy of test. Since the Missippian and lower beds in the Kansas and Oklahoma regions are now yielding large quantities of oil, why should not the extensive areas, underlain by deposits of Silurian and Devonian age, known to be present and petroliferous in character in the Canadian Great Plains, be expected to be commercially productive? Of course, owing to the extensive mantling of glacial deposits, the progress made in exploration will necessarily be slow and expensive. Structure drilling will have to be restored to in prospecting most of the Canadian Great Plains area. Already the Dominion Government has made provision for this by organizing the so-called "Boring Division" of the Canadian Survey for a drilling campaign with the view of increasing the information concerning the geologic formations which, over such a large part of the area, are concealed by glacial drift. However, taking into consideration all the facts, it is believed the conditions justify such exploration even though it is slow and costly.

As stated in the introduction of this paper, only a few geologists have had the opportunity to examine the geologic conditions and oil possibilities of the Mackenzie River basin. During the past six years, however, or since 1920, a number of geologists of the Canadian Survey have made preliminary examinations and published reports on some of the supposedly more promising districts. These investigations have followed, for the most part, along the course of Mackenzie River.

In the Wainwright-Vermilion district, Alberta, near the town of Wainwright, where oil was discovered in 1923 by the British Petroleum, Ltd., G. S. Hume has done considerable work and the following extracts are taken from his report:

> The regional structure of the Wainwright-Vermilion area has been presumed to be a terrace; that is, an area over which the beds are almost horizontal. In this area there is slight departure from the horizontal, which gives a regional dip of a few feet a mile to the southwest and on which a number of folds are superimposed. . . . . Information obtained from the wells drilled in the vicinity of Wainwright and Fabyan renders it certain that the oil and gas are associated with anticlines or upwarps of the strata, and that little or no success is likely to attend wells drilled in synclines.[1]

The Peace River district, which lies along Peace River and below the town of Peace River, has experienced considerable well drilling during the past few years, but thus far this drilling campaign has not brought favorable results.

Doubtless everyone is familiar with the famous tar sands of the Athabaska River region. The area centers around McMurray, extending up and down the river for a distance of more than 100 miles and 65 miles west and east of Athabaska River. This area represents, by actual outcrops, probably not less than 750 square miles. The impregnated sandstones are basal Cretaceous and rest on Devonian. Exhaustive reports on these tar sands and their possible commercial utilization have been made by S. C. Ells of the Canadian Bureau of Mines.[2]

[1] G. S. Hume, "Oil and Gas Prospects of the Wainwright-Vermilion Area, Alberta," *Summary Report, Geol. Survey Canada* (1924), Part B, pp. 8B and 13B.

[2] Sidney C. Ells, "Bituminous Sands of Northern Alberta," *Canada Dept. of Mines ,Mines Branch Publication No. 625*, 1924.

Following the discovery of oil north of Fort Norman, in 1920, the Canadian Geological Survey sent several parties into the Mackenzie River basin to study the geology and oil possibilities. During the years from 1920 to 1924, inclusive, the shores of Great Slave Lake and the valleys of Mackenzie River and its principal tributaries as far north as the delta of the Mackenzie were examined in a reconnaissance way. The general geologic information regarding the formations has already been briefly summarized and the more promising formations for oil accumulation pointed out.

The Devonian and Silurian in the vicinity of Great Slave Lake are probably too near the surface to afford much promise of oil accumulation under favorable structure. Farther northwest, between Great Slave Lake and Simpson, at the mouth of Liard River, the formations lie very flat, and it is stated that no dips greater than a few degrees were observed. Below Simpson the Front Range of the Mackenzie Mountains lies very near to the western side of the Mackenzie River valley. East of the valley is a prominent mountain uplift known as the Franklin Mountains, in which pre-Cambrian is brought to the surface. Between these mountains, in the structural basin, occurs considerable secondary folding. Some of these structures trend east-west or at a wide angle to the inclosing mountains. The discovery well at Fort Norman is stated to be on the southwest flank of a prominent structural uplift.

The Rocky Mountain front is bordered by a comparatively narrow zone of sharply folded and faulted rocks extending from the international boundary line northwest, with decreasing deformation, probably as far as Liard River, but the northern part of this belt is practically unexplored. East of this sharply folded and faulted foothills belt occurs a broad, synclinal plains area in which the local folding is very slight and is measured in feet per mile rather than in degrees. While this Great Plains area is one of prevailing low dips, it should be borne in mind that all of the Mid-Continent's most productive territory has been developed under similar structural conditions.

CONCLUSION

Of course, much is yet to be discovered concerning the details of sedimentation of the Canadian Great Plains area, such as the character, thickness, and extent of the source beds, the reservoir capacity of the oil-bearing formations, the interformational relations, the local structural features, the underground water conditions, and many other factors known to influence oil accumulation; however, when the size of this region, its broader geologic conditions, and major structural features are considered and compared with those of the United States which have produced such a preponderance of the world's petroleum during the last seventy years, one is forced to the conclusion that this area, as a whole, merits thorough, systematic exploration which, at present, has scarcely begun.

The writers believe that the Canadian Great Plains comprises one of the largest remaining undeveloped areas of sedimentary rocks having oil possibilities on the North American continent.

FOLDING OR SHEARING, WHICH?[1]

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ABSTRACT

Folding and shearing are the two types of deformation which may result from compressive stress in the earth's crust. The structures found in a given region depend on the type of deformation, which in turn depends on the original condition of the rocks at the time of deformation. Folding requires special conditions for its development, and only rarely is it the controlling type.

In the California Coast Ranges deformation has been governed by shearing, particularly along the great faults such as the San Andreas. This type of deformation began after the intrusion of the Sierra Nevada and Lower California batholiths, and was determined and controlled by them. The history of the California Coast Ranges is the history of a large number of fault blocks, each of which has acted differently under the stresses to which it was subjected, but is nevertheless related mechanically to the forces which govern the regional movements.

Deformation by shearing may produce faulting on a large scale, the fault blocks may again be sheared by secondary stresses, or the conditions for folding may exist within them, giving folds of the type found in the Coast Ranges. In addition to these structures, shearing from deep-seated compression may produce vertical uplift, resulting in tension at the surface and normal faulting. Most of the structural features of the earth's crust find their origin in one of these types of deformation.

California offers examples of all of them, and there seems to be some relation between oil accumulation and the type of structure. On the western side of the San Joaquin Valley there has been folding due to compression. Possibly this compression and the heat involved in the deformation has influenced the origin of the great oil fields of this region. On the east side of the valley, where the structures are due to tension following bulging by deep-seated compression, no oil has been found.

A more penetrating analysis of the mechanical development of oil-bearing structures is invited in the hope that it may lead to a better understanding of the problems of oil distillation and accumulation.

The question thus stated involves a distinction that is not commonly made in discussing the problems of structural geology, but which is of fundamental importance in the mechanics of structures bearing on the accumulation of oil. It is essentially a question of mechanics, in which the manner of yielding of rocks to pressure is involved.

The existence of pressure in the earth's crust in the past and present geologic ages is generally recognized, and it is clearly understood that the unit stresses have been sufficient to overcome the resistance of rocks to deformation. That is, the rocks have been crushed or have been obliged to bend, according to their nature. If they were crushed, they sheared. If they bent, they folded. And they adapted themselves to deformation by one or the other of these methods, according to the least stress involved in the change.

The idea of folding is very widely and generally accepted. It has its legitimate place in the development of such structures as we see in the Appalachians in sedimentary rocks that were not too deeply buried when deformed. It also has a place

[1] Read by Robin Willis before the Association at the Denver Meeting, September 23, 1926. Mr. Willis was introduced by Alex W. McCoy. Manuscript received by the editor September 30, 1926.

in the description of the minor anticlines and synclines of the Coast Ranges of California, although there shearing is the predominant structure. But the term "folding" is not correctly applied, in my judgment, to changes of form in massive rocks or in sediments which are so deeply buried that an arch cannot develop by horizontal pressure.

If the proper use of the term "folding" is thus restricted to sedimentary strata not under excessive load, then it is misleading to speak of a fold of the earth's crust. Similarly, it would be a mistake to talk about folds where the predominant effect is that of vertical forces rather than that of horizontal pressure, even though the vertical uplift may produce an arch which simulates the anticline of folded strata.

The misuse of the term "folding" would not be of much consequence if it did not involve misconceptions regarding the mechanics of deformation of rocks. But it does, and our inferences regarding unknown structures are so influenced by our interpretation of observed facts that we are likely to be led into mistaken assumptions and to spend large sums of money on a false hypothesis. For this reason it seems worth while to analyze the resistances which rocks offer to deformation and the manner in which they yield according to the law of least work in any case. We may begin with folding as the type which is best known and most generally assumed.

Folding is that phase of deformation which is produced when strata are arched up by horizontal compression. The force is applied to the edges of the beds and is transmitted in the beds themselves. Exception may be taken to this categorical statement on the ground that an inclined force may produce similar effects, but in that case we have to deal with the resolution of the inclined force into components, and the effects are not materially different. In this brief statement I shall not take up various alternative complexities, but restrict myself to the simplest cases, trusting that it will be understood that the variety of possible alternatives is not overlooked.

When a stratum of rock is brought under horizontal pressure in the earth's crust the pressure grows gradually and is transmitted in the direction of the bedding, provided the friction on the bedding planes offers less resistance than the rigid bed does. In that case, if any movement occurs, the force is resolved at the bedding plane into two components, one perpendicular to, and the other parallel with, the bed, and it thus remains in the stratum. A resistance equal to the active pressure is always developed, and the stratum thus comes under two equal and directly opposed forces. If it be flat, and particularly if it have great thickness, it may be crushed, that is, sheared, when the pressures attain sufficient intensity, but we are now dealing with the case in which it may fold. That case involves the conditions under which the stress transmitted in the stratum may deflect it from its flat position and cause it to arch up. It is well known that an initial dip or departure from uniform flatness is the effective condition which leads to the development of a primary anticline.

It is also generally understood that the compressive force is resolved into components at the initial dip, and that it becomes effective in producing an arch when the component at right angles to the bedding plane is sufficiently developed to lift the load that rests upon the up-arching stratum. It follows logically that the stratum must be strong enough to support the load which it lifts, and it has therefore been called *the competent stratum.* Incompetent strata, on the other hand, are those which are too thin or too incoherent to raise even their own weight.

If this concept of folding be accepted, the term should properly be limited in application to the development of competent structures in the sense just defined.

The strength with which a stratum of limestone or sandstone may lift an arch is limited to its resistance to shear. As long as bending and lifting involve less effort than shearing, the stratum will develop a fold when adequately compressed; but when bending and lifting become more difficult than shearing, then the latter phase of deformation will develop.

It follows that given a stratum which is competent at a certain depth, it will become incompetent—that is, it will be unable to rise in an arch—at some greater depth. For the increase of load gains with depth faster than the shearing strength, and will thus prevent the development of a competent fold at some depth which is determined by the strength of the rock. It follows that folding is a superficial phenomenon of the outer skin of sedimentary strata, and cannot be produced by compression of rocks at greater depths. Rollin Chamberlin has demonstrated this principle by elaborate studies and analysis, but it follows directly from the mechanical conditions which cover that type of deformation properly called *folding.*

The alternative type of deformation is *shearing.* By shearing I mean the tendency of any substance to part, or the actual parting, on planes which lie approximately at 45 degrees to the line of compression. It is often well developed in butter which has been pressed into molds. It is the phase of deformation that was produced in many of the models illustrated in the *Thirteenth Annual Report* of the Geological Survey, especially in the softer basal layers, and it is the type which appears in faulting and jointing in massive homogeneous rocks.

The development of shearing, as indicated above, is partly a function of depth. Even in sedimentary rocks, shearing becomes easier than folding at a depth below 5 or 6 miles; and widespread observation of rocks that have been more deeply bedded show that it is the one mechanical method of deformation at greater depths, and probably down to the zone where mechanical changes of form is replaced by recrystallization and metamorphism.

Shearing is, however, not merely a function of depth; for its perfect development it requires homogeneous resistances, as in the case of butter. The structureless character of butter affords opportunity for the development of partings on planes which are mathematically oriented and consequently perfectly flat, provided the external resistances are uniform. So also in rocks. Shearing develops ideally in homogeneous granite. It may also be sharply defined in soft clays, or in

bedded rocks, provided that the latter were so heavily loaded that the friction on bedding planes was equal to the shearing strength of the rocks themselves and the resistances of the mass as a whole were homogeneous. It often happens that strata are jointed by shearing when they have not been sufficiently loaded to produce homogeneous conditions in beds of diverse character, but then each stratum has behaved according to its peculiar nature and the joints vary in their attitudes and placing accordingly.

The orientation of shear planes in any but a homogeneous body is governed by lines of weakness. They are often deflected along bedding planes, and overlooked for this reason. They may also follow contacts between rocks of varying resistances.

It was not until I had spent several years investigating the structure of the Coast Ranges of California that I came to recognize the predominant importance of shearing as contrasted with folding. I had begun my studies in structural geology by investigating the extraordinary folds of the Appalachians. Shearing, as I saw it there, was produced by the development of a force-couple as a feature of overturned folds. I knew it only as an effect of two forces opposed to each other but not in one plane, as it is commonly described by Leith. I looked upon it as an incident, and regarded folding as the dominant phase of deformation of the earth's crust.

In my first work in California I looked everywhere for folds of the Appalachian type, that is, long, well-developed anticlines and synclines in parallel orientation. But they were not to be found. Folds in the Tertiary strata are everywhere short, locally developed, and cut off by vertical faults of much greater extent. I came to recognize that faulting is the dominant structure, and folding a minor effect.

The geologists who have studied the displacement on the San Andreas fault, which caused the earthquake of April 18, 1906, in northern California, were the first to recognize that that great fault is a shearing plane. Branner, Gilbert, Lawson, and Reid were associated in that study, and Reid published the analysis of the shear in his discussion of the earthquake in the report of the State Commission. The fact that the San Andreas fault is a great shearing plane which long antedated that particular earthquake is now generally recognized. The trend of the fault is in a general way from southeast to northwest, and the compression which produced it was oriented in a nearly south-north line, as is shown by the analysis of the movement observed in 1906 and various other related facts. The fault is traced 600 miles, from the Mexican boundary to Punta Arenas, a cape on the coast of northern California, where it passes under the ocean. Its extensions southeastward and northwestward have never been worked out, but it is obviously a structural feature of the first magnitude. It is also plainly a mechanical shear, the effect of well-defined pressure on rocks at great depths, where alone homogeneous resistances could exist over so extensive a surface.

The San Andreas is the largest shearing plane known in California or as yet identified anywhere, but there are many others in California which are of great

extent and take rank among the dominant features of the ranges. I will not refer to local details. Those who wish to study the systems will find them illustrated in the Fault Map of California published by the Seismological Society of America in 1923. But I wish to emphasize the fact that the major faults are very ancient features of the coast and are relatively simple in their arrangement, whereas there is an infinite number of minor secondary faults which affect the younger strata and which have developed as effects of component pressures resolved along the greater dislocation. The blocks cut out by the major and minor faults have often been rotated, dragged, and diagonally compressed in such a way as to produce minor folds which have had an important influence upon the accumulation of the great oil pools of southern California.

The process of faulting was not limited to any one geologic period. It has continued to dominate the structural development of the Coast Ranges since the Jurassic, and its effects have extended to the Sierra Nevada and the Basin Ranges. In the Coast Ranges it has controlled the surface expression of the country, together with all that that implies. Let us consider the conditions, since they bear directly upon the problems of the oil geologist.

We may regard the San Andreas fault as one of the oldest structures, if not the original structural feature, of California. It follows the eastern side of the batholith of Lower California and of the granodiorite outliers which extend north to about Latitude 37–30. Beyond that it follows the coast, and we are left to surmise as to what lies west of it. From Latitude 34–40 N., the batholith of the Sierra Nevada lies east of the fault. It outcrops only at a distance, except at the southern end, but by hypothesis extends under the Valley of California and under the Coast Ranges. The two batholiths are very rigid masses, quite incapable of folding, and have acted as struts to transmit pressure in the earth's crust. It is reasonable to regard the San Andreas fault as the surface on which the southwestern batholith has moved. Where the latter has impinged on, or approached, the Sierra batholith the great fault defines the Valley of California. Where the southwestern batholith is thrust against the mass of old gneisses and Paleozoic sediments of the southeastern section of the state, the fault defines the outline of the granodiorite intrusion.

According to this interpretation the Coast Ranges and the Sierra Nevada are provinces which were defined by the batholiths themselves and have been distinct geographic provinces since the beginning of the orogenic period. Since the geography of the Coast Ranges is of more immediate interest we may confine ourselves to that and describe it briefly.

Following the solidification of the granodiorite there came extensive eruptions of the basic intrusives of the Franciscan, which in turn followed the structural lines determined by the preceding batholiths. The basic eruptives have since been easy to shear, and the serpentine dikes are particularly apt to determine surfaces of displacement.

The subsequent faulting is too complex to be described in a comprehensive

manner, but its effect upon the paleogeography, the folding of Tertiary sediments, and the accumulation of oil has been marked. The basement rocks which extend beneath the sediments have been sheared into separate blocks that range from 10 to 30 or more miles in length, and from 4 to 15 miles or more in width. It follows from the laws of shearing that the blocks are wedge-shaped. The wedge may appear in the outline plan or it may give the block a boat-shaped bottom. But whatever the attitude of the wedge may be, it controls the direction of the resultant pressure in the block and determines the direction in which it will move when subjected to compression. There are many facts of structure which are best explained by this action, but I will mention only the direct results of observation.

Mount Tamalpais, a peak north of San Francisco, moved north by west at least 5 feet between 1854 and 1906 under the accumulating pressure that caused the great earthquake of the latter year. Since the pressure was relieved by the shock it has slid back 6 feet to the southwest. Both of these movements correspond to the displacements required by the form of its bottom surface, which is that of a large spall sheared off of the eastern side of the San Andreas fault.

Loma Prieta, a peak in the Santa Cruz Mountains, has moved consistently toward the southeast since 1854 and has attained a total measured displacement of 16 feet. The faults that converge around that mountain block form an acute angle at its northwestern corner and deflect the compression into a resultant that is directed toward the southeast. The mountain block obeys that pressure. It is also boat-shaped underneath and has risen like the hull of a ship under ice pressure.

The Santa Ynez range extends east and west along the coast west of Los Angeles. It is bounded on the north and on the south by faults that dip about 70 degrees under it from both sides. Tunnels driven through the block from south to north show a great deal of internal shearing and upward displacement with drag folds in sandstone. The effects are those which would be expected if the whole block, which is 75 miles long and 4 to 10 miles wide, had been forced up by pressure against the faults that converge under it. There is no doubt in my mind that that is the action which has lifted the Santa Ynez range. The pressure in this range is directed from south by west to north by east and has caused the mountain block to move 24 feet northward in the last thirty years. It also caused the Santa Barbara earthquake.

The actual movements that have been measured by the United States Coast and Geodetic Survey demonstrate the fact that the Coast Ranges of California consist of separate blocks which are now moving in diverse directions according to their forms and the resultant pressures developed in each block. There can be no doubt that they have moved in the same manner, under the same kind of control, since the beginning of the faulting process, with such differences of displacement as to direction and amount and such intervals of rest as the dominating pressures determined.

The paleogeography of the region has thus been fixed by the faulting. Where blocks have been forced up, there have been islands or peninsulas; where they have

been depressed, there have been straits or sounds. The movements of any one block may have influenced, but cannot have controlled another. Consequently, the conditions of erosion and of sedimentation have varied from block to block; the thicknesses and sequences of strata are unlike in immediately contiguous areas which are separated only by a fault plane; and unconformities occur with bewildering frequency, but local extent.

It may be noted at this point that the active force of compression from the Pacific has been intermittent. There have been periods of deformation separated by periods of quiescence. During the latter, the relief of the surface of the fault mosaic was reduced by erosion of the highs and sedimentation on the lows. It is possible also that relaxation of the horizontal pressure may have caused gravitative subsidence of the previously compressed and elevated ranges, permitting widespread deposition over the basement of the fault mosaic. The time of deposition of the Miocene diatomite is a case in point.

It follows from the diverse movements of the blocks that each block has developed structural peculiarities. We would expect that to be the case when the stratigraphic sequence which covers the basement rocks of one block is different from that which covers another. But it is also true that superficial structures are different even when the sedimentation has been the same over two or many blocks. This was the case to an unusual degree in the deposition of the previously-mentioned Miocene diatomite, the principal source of petroleum in the Coast Ranges. During subsequent displacements of the buried basement rocks, the blanketing sediments have been faulted and folded by couples and pressures developed in them in consequence of the deeper movements. The superficial structures in which oil has accumulated are secondary and local. The geology of the oil fields is correspondingly complex, and each field is a problem by itself.

It will perhaps be helpful in distinguishing between folding and shearing if we contrast the conditions of deformation in the Appalachians of Virginia and Tennessee with those of California.

We now understand that the folding of the Appalachians must be regarded as a superficial phenomenon, even though it involves a sedimentary sequence which attains the unusual thickness of about five miles. Measurements of the amount of folding show that the Paleozoic strata have been compressed horizontally to about 65 per cent of their original width; that is to say, that where the folded mass is now 65 miles across, it would, if flattened out, occupy 100 miles. This is a minimum measurement. It is apparent also that the western edge of the mass has not moved, for beyond the zone of folding westward the strata are but very slightly deformed. Accordingly, the eastern edge must have moved at least 35 miles toward the west. If we try to carry this compression down into the earth's mass to any depth we meet with insuperable difficulties. Such a displacement can have occurred only as the result of the movement of a comparatively shallow layer. In the folded rocks of the Appalachians we are dealing with the thin edge of a wedge whose bottom surface slopes from the Cumberland Plateau eastward under the Piedmont

Plateau and the Coastal Plain deep down under the Atlantic basin. The thrust faults of the folded Paleozoic strata, as well as the great thrusts traced by Keith in the Smoky Mountains, go down to the major thrust plane that underlies the entire structure. Compared with it they are what the Scotch geologists call minor thrusts. This at least is the concept which I entertain of Appalachian structure. It is thus placed in the class with the Scottish Highland type and compares in character and magnitude with the structural type which I recognized in the Andes of central Chile in 1923.

If this interpretation is correct, even Appalachian folding is subordinate to the great thrust, or sole, which underlies the entire eastern coast of the United States. The total horizontal displacement must have amounted to much more than 35 miles; 100 miles is not an excessive estimate. Whereas none of the anticlines involve a shortening of more than a very few miles at the most.

In thus recognizing very large horizontal movements, I lay myself open, considering the modern trend of thought, to the suspicion that I accept the views of Wegener. But I beg to point out that the displacement, as I have described it, requires a movement from the ocean against the continent, and, if we take account of both shores of the Atlantic, implies an expansion of the sub-oceanic mass. This is not the concept of continental drift.

The structural facts of California demand the recognition of shearing as the primary effect of pressure exerted in the continental margin, as has been stated. The shearing has produced faults which stand practically vertically at their outcrops. There is thus a marked difference from Appalachian structures, at least superficially. The reason is to be found, as I understand it, in the nature of the rocks which have been compressed.

The Appalachian zone of folding corresponded with a geosyncline filled with Paleozoic sediments. The stratified rocks could fold, and did, because that was the type of deformation which met with least resistance. In California the initial phenomenon was the intrusion of a large batholith which solidified as a holocrystalline mass of granodiorite. It constituted a massive strut that could not fold, but which, when forced to yield, did so according to the law of least resistance by shearing. Being a very large and homogeneous mass, it sheared on a very large scale. The major faults of California are therefore long and presumably deep.

The overthrusts of the Appalachians contrast with the upthrusts of California in the direction of movement. In the overthrusts it is up the dip, which lies at an average angle of 35 degrees. In the upthrusts the displacement is cheifly along a horizontal component parallel to the nearly vertical thrust plane. The vertical slip is relatively small. Thus, in the earthquake of 1906 the horizontal movement attained 21 feet, whereas the vertical did not exceed 1½ feet. The difference may again be interpreted as an expression of the law of least work, which requires that a shearing plane shall develop in the direction of least resistance in any mass which is subjected to sufficient, but unequal, pressures. Theoretically two planes should develop nearly at right angles to each other and intersect with each other in a com-

mon trace. In the Appalachian structure the trace was horizontal, or would have been if both planes had actually become planes of displacement; but the shearing plane which was directed downward met with such resistance that no displacement occurred on it. Its twin plane, on the other hand, being directed upward at an angle of 45 or 50 degrees, met with less resistance and became a thrust fault that, on entering the strata, was refracted to a somewhat gentler angle according to their dip.

In California the nearly south-north directed pressure produced two original sets of shears which intersected in a common trace; but that trace was nearly vertical instead of lying in a horizontal position, as in the Appalachians. And of the twin shears, that set which was oriented in the southeast-northwest planes became active, while the northeast-southwest directed set was absorbed by a greater resistance. We may speculate as we like about the original conditions that gave rise to this result—and I am not without pet theories on the subject—but to discuss them would lead into the discoidal theory. The shearing and the subsequent displacements are facts of observation.

We may now drop the comparison of Appalachian and Californian structures and consider the latter for the lessons that may be drawn from them.

Faulting in California is an active process which results in the direct development of topographic relief. Both valleys and mountains result from the displacement of blocks which have moved during recent geologic epochs and which are moving now. The action is so vigorous that the Coast Survey, as before noted, has by repeated precise triangulation measured horizontal displacements of stations amounting to more than 5 feet and even to as much as 24 feet in thirty years. Under these conditions uplift exceeds erosion to such a degree that individual mountain blocks stand relatively high because they are being pushed up so much faster than they can be worn down.

The rapid rate of uplift leads one to look for pronounced fault scarps, but they are generally not found, even along the largest and most vigorous faults. It was not until I had examined several hundred miles of the San Andreas fault that I gave up the idea that a fault scarp is at least a common feature of an active fault. In California more of the great faults lie along valleys from which the two slopes rise gently on both sides. Frequently the hills have a gently swelling profile, one which is steepest near the fault, but which curves back in an arch and which may extend clear across the summit even of a high mountain ridge.

The abrupt fault scarp is characteristic of those sections along which the upthrust fault block consists of solid sandstone or massive granite. The swelling profile occurs where the fault block is composed of crushed sandstone, shale, crushed granite, or serpentine. The difference in external form is an effect of the internal structure. The scarp is the face of a solid block that has moved as a whole without changing its shape. The swollen profile represents the change of form which has been produced in a crushed mass as the thousands of little blocks have slipped past each other. The latter is the more common form in the Coast Ranges.

The little blocks which constitute a crushed mountain are cut out by secondary jointing, which is carried to the *n*th degree. Some blocks may measure a hundred feet or more on a side, but more of them scale but a foot or two. They are produced by secondary shearing, which in turn is an effect of the intense compression imposed upon the mountain mass by the forces that are raising the Coast Ranges and the Sierra Nevada. The dominant effect of that pressure is to cause horizontal displacement, as we see in the actual movements of the 1906 earthquake and in the changes of position of triangulation stations; the forces of compression act, therefore, tangentially, that is, horizontally. In the swollen mountain forms, nevertheless, they have caused vertical displacements.

Were the shearing and slipping uniformly developed in any large mountain mass, its surface would rise uniformly and would become a plateau. That condition may develop, hypothetically at least, where the action is very deep seated, but it is not to be looked for in superficial structures like the Coast Ranges. There the variables are too numerous. Granite, sandstone, serpentine, and shale shear very differently, adhere very unequally, and slip with greater or less ease. The original structures, whether massive, bedded, sheared, or schistose, also affect the result. Hence there is very great inequality in the degree of vertical displacement and in its distribution throughout a given mountain block. Many blocks are covered with a blanket of sediments which are so constituted that they find relief by true folding when the basement below them is shortened by shearing. The superficial forms vary accordingly. There is opportunity here for extended discussion of the mechanical effects of shearing and distortion, including folding, but I shall confine myself to certain cases that may be of significant interest in connection with petroleum.

Let it be assumed that pre-Miocene displacements cut out a wedge-shaped mass of the basement rocks, which might be schist, granite, or serpentine, and left it in such shape that it would rise if subsequently compressed. Suppose it to have been covered with Miocene diatomite, which also extended widely over adjacent blocks. Then during later episodes of compression, such as that at the close of the Miocene and such as the one now in progress, the block would be elevated and would become a hill or mountain. The case that I have in mind is that of San Pedro Hill, near Los Angeles, which has become widely known by the descriptions of the raised beaches that encircle it and which demonstrate its displacement upward. The adjacent shores do not share in the uplift. They, on the contrary, are buried beneath Pliocene strata and have subsided as the hill has risen. In consequence of the opposite movements in the hill and in the block northeast of it, the strata in the latter have been dragged up along the fault which runs past the northeast side of the hill. They thus dip down, away from the hill, and the compression has produced a syncline. The development of the syncline required an anticline northeast of it, still farther from the hill, and there we find the Torrance oil field.

A few miles farther south the anticlines of Signal Hill and Huntington Beach

stretch along the Inglewood or Coast fault, immediately east of it. In these examples the initial effect of compression in deep-seated rocks was, presumably, to establish an initial dip in the overlying strata directly toward the fault, and subsequent compression of the foundation rocks resulted in the elevation of the anticlines parallel with the fault itself. In this case there was no horizontal displacement along the fault itself, and consequently the force of compression acted at right angles to it.

In another case the series of short anticlines or domes that constitute the Santa Fe Springs, Coyote Hills, and Richfield oil fields resulted from compression combined with drag along the adjacent Puente Hills fault. The block southwest of that fault moved northwestward past the block on the other side of it. The drag combined with the pressure perpendicular to the fault plane and gave a resultant pressure, which was directed toward the south. The effect upon the strata was to compress them in that direction and to force them to wrinkle in short anticlines that are oriented approximately from west to east.

It appears from these instances in which the exploitation of the oil fields has supplied detailed information that vertical and horizontal displacements on fault planes may materially affect the orientation of folds. It has been proved by experience that the mechanical analysis of the forces involved could lead to the detection of productive structures, whereas the somewhat less satisfactory experience of dry holes has suggested an interpretation that may explain their barrenness, at least in California.

It is generally assumed that all anticlines are caused by horizontal compression, but that is not necessarily so. A dome or cigar-shaped uplift may be raised by vertical pressure. The mechanical effects are different in the two cases, and the accumulation of petroleum may be favored in one structure or the other according to provincial conditions. Let us contrast the two.

When an anticline is produced by horizontal pressures the strata slip past each other on bedding planes in adjusting themselves to the compression on the concave side of each curve. They are squeezed, not stretched. Faulting is overthrusting, if any. Whatever energy is converted into heat is developed by friction within the folds. Being confined, the heat may produce distillation of petroleum or promote its movement. Movement of the oil is along the bedding planes or in porous strata between impervious beds. All of these conditions tend to promote the accumulation of gas or oil in the anticlines and to confine it in the strata.

When an anticline is developed by vertical uplift the effect originates outside of the superincumbent strata in some deep-seated mass. The latter is by hypothesis undergoing shearing in consequence of horizontal compression in a zone below the stratified rocks and is elongating upward in the manner already described. Rising beneath the sediments, it pushes them up. The effect is to stretch the strata over the upswelling mass. Faulting is normal faulting. The structure is under tension and is open upward. The conditions are less favorable for the development or confinement of heat energy, and consequently not likely to promote the distillation of

petroleum from relatively raw organic materials. If oil is for any other reason already present, it will tend to rise along the normal faults and be caught in the incidental drag folds.

California offers excellent illustrations of the two types of structure.

The great accumulations of oil in the Los Angeles fields and along the southwestern side of the San Joaquin Valley are gathered in folds which have developed from strata under horizontal compression. Although the strata are traversed by thrust faults, to which the folds are incidental, the beds have been folded by pressure transmitted from their edges and they have adjusted themselves to the development of the competent structures, with all that that implies in the way of friction and thrust. In similar structures I have observed that coals, which by their geologic age should be lignites, have been altered to bituminous varieties. The metamorphic effect cannot have been less where the organic material was petroliferous, and I regard the occurrence of extraordinary quantities of oil in these structures as something more than a coincidence. I regard the oil as a metamorphic product of locally intense conditions.

Contrasting strikingly with the productive fields that stretch along the western side of the San Joaquin Valley from Elk Ridge to Coalinga is the eastern side north of the Kern River field. Both the valley floor and the foothills of the Sierra Nevada have there been examined and to some extent drilled, without success, except for gas. Recent investigations by B. F. Hake show that the zone is one of normal faulting. The western slope of the Sierra Nevada and the adjacent strip of the valley are in tension. My own studies of the eastern slope of the Sierra Nevada have satisfied me, contrary to my previous opinion, that the faulting on that side is also normal. It follows that the Cordillera is up-arched by vertical forces, as was recognized by Gilbert in 1875, and that it is in tension across its entire superficial section. I regard this as sufficient explanation of the absence of petroleum fields along the eastern side of the San Joaquin Valley.

In the eastern United States the conditions differ radically from those in California. There is but little active faulting, and what there is, is normal faulting. Folding took place at the close of the Paleozoic in the Appalachian belt and in Arkansas. After a prolonged period of quiet a new orogenic period was inaugurated in the Miocene and it has raised the Appalachian swell and also other dome-shaped highlands, which are well known.

They are not folds in any proper sense of the term. They are far too broad and low to be arched up by a tangential force acting in the line of the strata, even where the strata still lie flat, or nearly so. They are the effects of a vertical force which, according to the hypothesis already outlined, is itself a result of deep, subcontinental compression.

Several years ago I had an interesting correspondence with Mr. Wallace Pratt regarding the character of the Mexia fault. Being then under the impression that compression and tension could not simultaneously affect the same segment of the earth's crust, and believing the Texas region to be under compression, I tried to

explain that normal fault as a steep thrust, but I did not succeed to his satisfaction or my own. I was in the position of the president of a construction company who could not understand how his engineer could swing two electric cables within three feet of each other across a mile-wide span without taking a chance that they should swing together and short-circuit the line. "I will hang one over the other," said the engineer. "Oh!" said the president.

I think that is the solution of the problem that has so long puzzled me: the occurrence of normal faults in regions where other phenomena clearly indicate the existence of far more general and powerful forces of compression. The compression is deep; the tension is superficial. The latter is the logical, mechanical effect of the former, through the action of deep-seated shearing.

One of the most complicated associations of compression and tension is to be found in the Rocky Mountains. Not only are strata in certain districts folded according to the principles of competent folding under tangential pressures, but there are remarkable overthrusts of very low dip and great displacement. The evidence indicates eastward movement in consequence of pressure that pushes against the strata within a few thousand feet of the surface, or less, although it may originate at considerable depth. Associated with these tangential effects there are dome-like uplifts and plateaus which have been raised by vertical forces. There are also volcanic extrusions. I believe the riddle can be read by the key we now possess. The combination of shearing and vertical displacement with extensive overthrusts was produced in some of the models compressed in 1886–87 and described in "Mechanics of Appalachian Structure," but I did not know how to interpret the results. I was looking only for folding, and was blind to the significance of shearing. I now look upon shearing as the characteristic mode of deformation in the foundations of the continents, and attribute the fact that they stand relatively high to the vertical elongation of the masses in conforming to the compression of the deep-lying basement rocks. The elevation of the surface is independent of the fact that the tangential pressure may cause horizontal displacement of such magnitude that it extends to the surface and there produces the effects of folding and overthrusting.

The recognition of this fact has shed some light on other problems that have long puzzled me. For instance: Why are there those features of the earth's surface that we call ocean basins and continents? The complete answer is a long one, and I may never know it all, but I am inclined to think that we make a step toward answering the question if we postulate that *the underbody of each ocean basin is the seat of dynamic activities which cause it to expand horizontally, whereas the continental masses are relatively inert and are compressed.* Thus the continent of North America is compressed between the Atlantic, the Gulf of Mexico, and the Pacific underbodies.

By *underbody* I mean a mass which lies beneath an oceanic deep, or other depression of the surface, and extends down into the zone where high temperature, metamorphism, and fusion are the normal variables of the lithosphere. The down-

ward extension must amount to several hundred miles if the effects of expansion penetrate the continent as far inland as they seem to.

The underbody of the Atlantic, according to this hypothesis, expanded effectively during the late Paleozoic and crushed in the margins of North America and northern Europe, shearing the deeper rocks and folding the superficial layers. After a long period of quiescence, the activities beneath that oceanic deep were revived during the Miocene, and they still continue effective, as is shown by the warping of the eastern part of the continent. It is a vertical effect accompanied by normal faulting.

The underbody of the Gulf appears also to be active, but only in very moderate degree, as is indicated by the uplift of the plateau of Florida and the Llano upwarp in central Texas. In the latter case it also is accompanied by normal faulting, the Balcones and Mexia zones.

The underbody of the Pacific is exceedingly active and has been so, since the late Mesozoic, throughout its entire extent. The shores of the great ocean exhibit coast ranges which are raised chiefly by shearing, with subordinate folding. The conditions, wherever I have been able to observe or to analyze them, are similar to the California type, although marked differences must be recognized. The vigorous dynamics of the so-called "Pacific" contrast strikingly with the barely nascent action of the Atlantic basin.

If the continent is gripped between the underbodies of the oceans on either side of it, the pressures must penetrate from shore to shore across its entire width, but far below the surface. The effect at the surface in past ages, or at present, would depend upon the internal structure of the continental mass, which would give rise to geosynclines and geanticlines; upon the development of great shearing planes, that would provide opportunity for the extrusion of igneous rocks; and upon the structure of the surface layers, such as stratified sediments, which could fold in yielding to appropriate stresses.

It is obvious that the influence of the pressure from one or another sub-oceanic mass would be more distinctly observed on that side of the continent adjacent to it, but the penetration of that pressure into the body of the continent might depend upon the depth of action and other conditions not evident to us. Something, however, can be inferred from the dates of organic activity in different parts of the continent. Thus it is apparent that the Appalachian revolution did not affect the regions west of the Cincinnati Arch, whereas the Laramide disturbance may be attributed to Pacific activity on the basis of coincidence of dates.

The orogenic history of the Rocky Mountains runs parallel with that of the Pacific coast in a manner that strongly suggests a common dynamic history. When to that we add the evidence of the great overthrusts toward the east, we are obliged to attribute the displacements to the pressure from the Pacific, unless we adopt some entirely different hypothesis of orogeny.

My object in this paper is not to draw you into a discussion of theories, but to indicate the desirability of distinguishing between three different structural de-

velopments that are now too commonly confused under the name of folding. I mean: (1) folding proper, the Appalachian type; (2) shearing, which appears at the surface in the form of long thrust faults independent of folds, but is associated with minor folds within individual fault blocks—the California type; and (3) warping, the effect of deep-seated shearing, vertical elongation of the sheared mass, tension of the surface, and normal faulting.

Petroleum geology has long since outgrown the primer of geology. It is using the most advanced methods of research. In offering these suggestions regarding types of structures I would invite a more penetrating analysis of the structural aspects of the problems.

DISCUSSION

E. Russell Lloyd: I think that Dr. Willis might well have used the southern Rocky Mountains as a type example of his third class of structural development, that is, warping, the effect of deep-seated shearing, with vertical elongation of the sheared mass, tension of the surface, and normal faulting. Lee[1] has pointed out that the movements which gave rise to the Rocky Mountains of Colorado were essentially vertical uplifts. There is a sharp distinction between the highly folded and overthrust mountains of the Canadian and the Montana Rockies and the broadly arched or domed mountain uplifts such as the Black Hills, Bighorns, Wind Rivers, Uintas, the Colorado Rockies, and many others. The folded mountains are represented as far south as the north-south ranges of eastern Idaho and western Wyoming, where a thick sedimentary series is thrown into a complicated network of folds and thrust faults.

The big fault on the north flank of the Uinta Mountains, a similar one on the north side of the Beartooth Mountains in Montana, and others less well known have been described as thrust faults, but they are very different in type from the overthrusts in the folded mountains. They are nearly vertical and are caused by the upthrust of the mountain mass, first arching and then breaking the flanking sedimentary strata. Strata adjacent to such faults are generally turned up vertically, or nearly so, and in some places are slightly overturned away from the mountains. In general these faults grade into the simpler type of structure in which the whole sedimentary series is upturned against the mountain front. This type of fault is well represented at Golden.

The arching up of the strata against, or over, the upthrust mountains and the attendant phenomena of faulting and secondary adjustments are of great importance to the Rocky Mountain petroleum geologist, inasmuch as most of the smaller structural features, including the greater number, if not all, of the oil-bearing domes or anticlines in the Rocky Mountain region are of the same general type genetically as the major uplifts.

Irwin[2] has pointed out that many oil fields developed on anticlines or domes are characterized by transverse or radial normal faults. These were obviously developed by tension due to vertical upthrust, and represent a phenomenon to be expected from the mechanics of such upthrusting.

[1] Willis T. Lee, "Building of the Southern Rocky Mountains," *Bull. Geol. Soc. Amer.*, Vol. 34 (1923), pp. 285 ff.

[2] J. S. Irwin, "Faulting in the Rocky Mountain Region," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10 (1926), pp. 105–29.

Upthrusting due to deep-seated shearing may give rise to anticlinal structure unfavorable for oil in California, as Willis says, but this is certainly not true in the Rocky Mountain region. One is led to wonder if anticlinal structure caused by true folding might be more favorable. So far very few such structures have been tested.

A very large number of Rocky Mountain anticlines are characterized by a sharp flexure on one side and a much more gentle slope on the other. Such lines of sharp flexure in many cases extend long distances. They very probably grade downward into nearly vertical faults, which may, in turn, be similar in mode of origin to the great California faults.

One point of very practical significance comes up in this connection. In an asymmetric anticline it has been generally assumed that the subsurface axis is shifted toward the side which has the lower dip. This would be the normal result in an anticline caused by true folding. On the other hand, where the anticline is a result of upthrusting, the side with the steep dip is likely to pass downward into a fault, in which case the subsurface axis would shift toward the steep flank. It is generally known that the subsurface axis in the Cat Creek Field, Montana, and in the Grass Creek and Lance Creek fields, Wyoming, are shifted toward the side with the steeper dip.

It seems to me that this is probably the rule rather than the exception. If so, there are undoubtedly a number of anticlines in the Rocky Mountain region which have been improperly tested.

W. A. J. M. van Waterschoot van der Gracht: I have followed Dr. Willis' paper with the keenest interest and greatly enjoyed his excellent comparisons of the widely different structure of the western and the eastern rims of the North American Shield: On the western side intense shearing by pressure from the west, against a continental rim, containing great rigid struts of batholiths of granodiorite, with intervening minor intrusions of basic rocks; on the eastern side predominant folding and overthrusting of some 25,000 feet of the sedimentary sequence of a great geosyncline by pressure from the east; the western orogeny, dating principally from the Middle Mesozoic and largely influencing sedimentation and still active; the eastern movement being largely Paleozoic, but with several minor activations later.

The picture is excellently drawn and very lucid. I am in thorough accord with the author's analysis of the western wedge-mosaic, as well as with his conception of the deepest underlying structure of the Appalachians.

When, however, we come down to primary causes, we differ. Although Bailey Willis accepts great horizontal movements, particularly in the deep basement, as I do, he is very careful to make it clear that he does not want to be suspected of adhering to Wegener's theory of relative continental drift. I knew he would!

I do not want to raise this question *brulante* just now; I hope to have that pleasure soon in New York. However, I want to point out that I consider Bailey Willis' theory of "oceanic underbodies," notably for the Atlantic, still more difficult to conceive than Wegener's drift, especially since John Joly so very nicely helped along this latter theory. Willis does not say what these underbodies are. We are only told that from time to time they vigorously expand laterally. I know that the author does not accept W. Hobb's oceanic arch pressing against its abutments, but considers it as mechanically untenable, as I do. This implicitly also must refer to Rollin Chamberlin's sinking oceanic segments. Then what causes this expansion of the "underbodies?" It could scarcely be anything else than their increase in volume by fusion. This might cause an increase in volume of

basic rocks up to a maximum of 10–12 per cent. But then these underbodies are no longer rigid! This fusion would also imply a very considerable bulging of the floor of the oceanic basin, still vastly more increased by isostasy, because the density of the "underbody" would also become very much reduced. This would offset the lateral thrust and might even cause expansive stresses!

I also have some quarrel with the author's otherwise quite correct statement that, if the effect of sub-oceanic expansion penetrates the continents as far inland as these pressures evidently do, these "underbodies" must extend downward several hundred miles. They could scarcely be sufficiently rigid at that depth (*more* rigid than the continent!) to exert a lateral push of this kind, and certainly not permanently, if Joly is at all right.

If, on the contrary, we accept drift of the continents, we have all the push we need from the Pacific Ocean against the west coast of North America—the enormous resistance of the ocean floor. But how for the Atlantic coast? I do not believe that the westward push in the Appalachians was from the Atlantic Ocean at all, and I consider that there was no Atlantic Ocean at that time. There was, to my belief, a geosynclinal, old Paleozoic sea between what is now North and South America on one side, and Europe and Africa on the other. This geosyncline was closed by the successive Caledonian, Acadian, and Appalachian orogenies, which spread westward in their successive phases. What we see on the Atlantic coast of North America is the western flank of this great Paleozoic system, actively pushed to the west, in accordance with the views of L. Kober (and R. T. Chamberlin). There was no Atlantic since old Paleozoic time until the old rift reopened in the later Mesozoic, and principally the Tertiary, through the relative lagging behind of Eurasia and Gondwana and the Americas drifting westward more rapidly. It is then that, naturally, the west coast of America becomes "exceedingly active," but compressive stresses *from the east* cease. We do not need these to explain the broad Tertiary warping of the entire American continent: deformation through drift is more than sufficient.

But I do not want to go further into debating all this now. I merely wanted to make this remark. Furthermore, it takes nothing away from the correctness of the lucid description of the resulting actual structures, which would be the same, whatever may have been the *primary* cause of the stresses through which they originated.

ORDOVICIAN STRATA IN DEEP WELLS OF WESTERN CENTRAL KANSAS[1]

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ABSTRACT

Several of the deep wells of Russell County, Kansas, penetrated green shales containing abundant fossils of species characteristic of the Decorah shale of the Ordovician system. These fossils are not known from any other system. The strata overlying the green shales seem to belong to the Pennsylvanian system. At any rate, strata containing Pennsylvanian fossils occur but a short distance above the green shales. The Pennsylvanian strata seem to belong to a time not older than the Douglas stage. Beneath the Ordovician green shales are several hundred feet of more or less crystalline limestones—shown as sandstones in some of the drilling logs—in which no fossils have been found. It is suggested that these limestones are of early Ordovician or Cambrian age.

The recent publication of four papers[2] giving data relating to the subsurface stratigraphy and fossils from deep wells of some parts of western central Kansas has suggested that it may be of interest in this same connection to publish information derived from studies of well samples obtained in the same general region, the samples being of particular interest because of their containing Ordovician fossils in considerable numbers.

The materials which bear on the problem of the title were obtained from the Phillips-Valerius (Sec. 3, T. 13 S., R. 13 W.), Murphy-Merriam (Sec. 11, T. 12 S., R. 13 W.), Beatty (Sec. 16, T. 12 S., R. 13 W.), Fairchild (Sec. 36, T. 12 S., R. 13. W.), Worley-Liggett (Sec. 34, T. 10 S., R. 15 W.), Haise—Producers and Refiners (Sec. 24, T. 12 S., R. 15 W.), and Milke-Findeiss (Sec. 20, T. 12 S., R. 15 W.) wells, all of Russell County, Kansas. Most of the samples from the Phillips-Valerius well were obtained by the writer. Some samples from this well and the samples from the other wells were collected by the geologic staffs of the Amerada Petroleum Corporation and the Carter Oil Company and were obtained through the kindness of Sidney Powers and D. K. Greger.

[1] Manuscript received by the editor October 8, 1926.

[2] R. C. Moore, "Fossils from Wells in Central Kansas, Part III, Geology of Russell County," *Geol. Survey of Kansas, Bull. 10* (1925), pp. 94–104; "Early Pennsylvanian Deposits West of the Nemaha Granite Ridge," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10 (1926), pp. 205–16.

M. N. Bramlette, "A Subsurface Correlation of the Stratigraphic Units from Russell County to Marion County, Kansas, Part II, Geology of Russell County," *Geol. Survey of Kansas, Bull. 10* (1925), pp. 86–93.

J. A. Udden, "Occurrence of Ordovician Sediments in Western Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10 (1926), pp. 634–35.

The Phillips-Valerius well was drilled to a depth of 3,730 feet.[1] The log of this well, from the depth of 3,000 feet to the bottom is as follows:

	Feet	Feet
Limestone	40	3,040
Sandstone	5	3,045
Limestone	35	3,080
Shale	103	3,183
Limestone	32	3,215
Brown shale	60	3,275
Red rock	10	3,285
Limestone	5	3,290
Sandstone	10	3,300
Broken limestone	10	3,310
Red rock	30	3,340
Green shale	40	3,380
Red rock	20	3,400
Sandstone	10	3,410
Limestone	320	3,730

Some of the strata of the lowest 320 feet are shown in the driller's log as sandstone or sandy limestone, but microscopic examination shows that essentially the whole of each sample consists of calcite or dolomite, probably the former, as solution takes place very readily in cold hydrochloric acid. Some samples contain chert. There is a sandstone, however, at the depth of 3,720 feet, as a sample from that depth consists almost entirely of angular and subangular grains of quartz.

The Pennsylvanian strata in this well probably extend to the depth of about 3,310 feet, or the level just above or within the red rock just below that depth. Pennsylvanian fossils were found in samples from 3,160 feet,[2] making it certain that the rocks of this system extend to that depth, and as the lithology, except for the red rock from 3,275 to 3,285 feet, suggests no indication of a break, the system is assumed to extend to the greater depth. The red rock from the depth of 3,310 to 3,340 feet is interpretable as a residual soil. This is surmise, as there is no positive evidence to this effect. The base of the Pennsylvanian may be in the red rock from 3,275 to 3,285, but as no fossils were obtained from 3,160 to 3,340 feet, it is not possible to make a definite statement. At any rate, the zone in which the base of the Pennsylvanian must occur has a thickness of only 180 feet.

The green shale from 3,340 to 3,380 feet contains an abundance of minute fossils and fragments of larger forms. Sixteen species have been identified. No fossils were found in the red rock or the sandstone beneath the green shale. Many samples of the limestone from 3,400 feet to the bottom of the well were carefully

[1] Samples received from Dr. Powers indicate that the well was drilled to the depth of 3,810 feet, or 80 feet deeper than the figures obtained by the writer; as all of the samples from horizons below the green shales show a depth of about 80 feet greater than those given below, it is obvious that no additional early Paleozoic strata are involved.

[2] Also noted by Bramlette and Moore, *op. cit.*

studied, but no fossils were found in any of them. The fauna of the green shale consists almost wholly of bryozoans, with some of the species represented by many small fragments, but it is probable that could the shale be seen in surface exposures, large specimens of forms other than bryozoans would be found. In addition to the bryozoans there were found small fragments of gastropods of undetermined species, two entire young brachiopods of two species, fragments of two additional species of brachiopods, a single ostracod and a fragment of the pygidium of a trilobite. The forms which have been identified are as follows:

Fragments of pleurotomarid gastropods
Peterygometopus ? sp.
Primitiella limbata Ulrich
Dalmanella cf. *emacerata* (Hall) fragments
Rhynchotrema minnesotensis Whiteaves
Strophomena or *Rafinesquina* sp. fragments
Zygospira nicolleti Winchell and Schuchert

Arthropora simplex Ulrich
Batostoma fertile Ulrich
Escharopora subrecta Ulrich
Homotrypa minnesotensis Ulrich
Pachydictya fimbriata Ulrich
Pachydictya foliata Ulrich
Rhinidictya exigua Ulrich
Rhinidictya mutabilis Ulrich
Stictoporella angularis Ulrich

This fauna obviously is that of the lower third of the Trenton shale ("Green Shales") of the early Minnesota Geological Survey reports, or the Decorah shales of later nomenclature.

The green shale of the Deissroth well occurs from 3,341 to 3,373 feet, and the forms identified consist of *Dalmanella* cf. *emacerata* (Hall), a small *Lingula* which appears to be *Lingula riciniformis* Hall, and the central lobe with small attached portions of the pygidium of a small trilobite of Ordovician aspect.[1]

The green shale of the Murphy-Merriam well occurs from 3,670 to 3,695 feet, and possibly deeper. The determined fossils from the shale samples studied are as follows:

Dalmanella sp. fragment
Rafinesquina or *Strophomena* sp. fragment

Homotrypa minnesotensis Ulrich
Rhinidictya exigua Ulrich
Rhinidictya mutabilis Ulrich

The Carboniferous in this well seems to reach the depth of 3,650 feet, as suggested by the presence of crinoid segments, fragments of a strophomenoid brachiopod of late Paleozoic aspect, and fragments of what seem to be small fusulinoid protozoans.

The Beatty well found the green shale from 3,750 to 3,500 feet, and samples therefrom yielded fragments of a pleurotomarid gastropod and many specimens of *Homotrypa minnesotensis* Ulrich and *Stictoporella angularis* Ulrich, and rarely specimens of *Escharopora exigua* Ulrich.

[1] The samples of the green shale from this well which were studied by the writer seemed to be barren of fossils. The forms listed were received from D. K. Greger and Sidney Powers.

It seems very probable that the horizon of the green shale was penetrated in the Milke-Findeiss well, as samples of green, gray, and red shales without fossils, reported from 3,370 feet, resemble the fossil-bearing Ordovician shales of the other wells and do not resemble the Pennsylvanian shales. Moreover, beneath the shale horizon of this well are limestones which are like those beneath the Ordovician green shale of the other wells. The Ordovician green shale may also have been penetrated in the Worley-Liggett well, as a little green shale like that of the Ordovician was found in a sample from 3,450 feet, and the limestones of greater depths resemble those occurring beneath the Ordovician green shale. The evidence of the samples, however, is not as clear as one might desire, and the depths do not appear to be sufficiently great. It also seems certain that the Fairchild well penetrated the Ordovician. The well was in the Pennsylvanian at 3,070 feet, as *Fusulina* was found at that depth. It was in limestones essentially identical with those below the Ordovician green shale at 3,460; and a sample from that depth, although largely composed of limestone, contains very finely powdered green and black shale. The well was in red shales whose samples yielded no fossils from 4,270 to 3,295 feet. No samples have been seen from 3,070 to 3,270 feet and from 3,295 to 3,440 feet.

Below the green shale of the Phillips-Valerius well are 320 feet of crystalline limestones with a sand layer near the base. Samples from 3,440 to 3,530 feet of the Fairchild well show the presence of essentially similar limestones. Similar limestones were penetrated in the Deissroth, Beatty, Haise—Producers and Refiners, Worley-Liggett, Murphy-Merriam, and Milke-Findeiss wells. No fossils were found in any of these limestones. On the basis of these limestones it is considered that the Ordovician or older strata were encountered in these wells, even if the writer has no evidence that the fossiliferous green shale is present.

It is very probable that the Ordovician was penetrated in the Vesper or Middlekauff well (Sec. 10, T. 12 S., R. 9 W.) of Lincoln County. This well was drilled to a depth of 3,472 feet and commenced on a considerably lower horizon than the Russell County wells, but not a great deal may be determined from the log available to the writer, and no samples have been seen. The chart of Plate VI of *Bulletin 10* of the Geological Survey of Kansas indicates that the Ordovician was penetrated in this well and also in the Denmark well (Sec. 9, T. 11 S., R. 8 W.); but, if such was the case in the latter, the Ordovician strata have a very different lithology as far as shown by the driller's log seen by the writer. Where the lithology is so very different in such a short distance it seems preferable to assume irregularity of the surface on the Ordovician, with downward extension of the overlying strata.

The Ordovician also has been found farther to the east in northern Kansas in a well in Washington County (Sec. 3, T. 3 S., R. 4 E.). A red shale in this well from 3,005 to 3,037 feet and a blue shale from 3,037 to 3,045 feet yielded fragments of species of *Orthis* sp., fragments of a rhynchonelloid brachiopod, and bryozoa identified by Bassler as *Rhinidictya mutabilis* Ulrich, *Stictoporella angularis* Ulrich, and *Homotrypa minnesotensis* Ulrich.[1]

[1] D. K. Greger, letter of October 28, 1924.

Two other very deep wells of this section of Kansas—one to the east, the Sheriden test in Ellsworth County (Sec. 21, T. 15 S., R. 6 W.); the other to the south and west, the Whiteside well in Hodgeman County—are not known to have reached the Ordovician. The Sheriden well was drilled to a depth slightly in excess of 4,000 feet, and is not known to have encountered the horizon of the Decorah shale, although it is possible that the horizons of the underlying limestones were penetrated in the lower portion of the well. A sample from 3,500 feet contained an abundance of what seem to be small *Derbya crassa*.[1] The Whiteside well was drilled to the depth of 4,055 feet and found Carboniferous rock to at least 4,000 feet, with the possibility that it extends to the depth drilled.[2]

The age of the limestones beneath the green shale has not been determined, as no fossils permitting this determination were found in any of the samples. It is possible that the red rock which has been found in some wells beneath the green shale may represent a residual soil, and, as no St. Peter sandstone has been found in any of the wells, it may be that the red rock represents the time interval of St. Peter deposition, and the limestones may represent the Lower Magnesian of the Upper Mississippi Valley. On the other hand, some portions of the Cambrian system may be represented in these limestones.

SUMMARY

Ordovician strata containing middle Ordovician fossils (Decorah shale horizon) in sufficient number and excellent preservation to make certain the identifications are known to occur in the Phillips-Valerius, Deissroth, Beatty, and Murphy-Merriam wells of the Russell County region of Kansas, and strata of the same horizon have been found in a well in Washington County, Kansas. Strata of the same horizon probably were penetrated in the Fairchild, Haise—Producers and Refiners, and Milke-Findeiss wells and may have been reached in the Worley-Liggett well. Limestones of Ordovician or an older system have been penetrated in all of the Russell County wells named, with the possible exception of the Worley-Liggett. It is probable that the Ordovician was reached in other wells of the Russell County region, but no samples indicating such have come to the writer's attention.

[1] The writer has had the opportunity of examining three sets of samples from this well (Marland Oil Company, Carter Oil Company, and Keys Petroleum Company, the last-named the drilling company). The fossiliferous 3,500-foot horizon containing *Derbya crassa* (not more than one-third grown) was seen in two of the sets. Bramlette (*op. cit.*) expressed the view that the part of the sample containing *Derbya crassa* represents cave. Ley opposes this view, and is of the opinion that the brachiopods came from the level of derivation (H. A. Ley, "The Sheriden Test, Ellsworth County, Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10 [1926], p. 199). The writer is inclined to the view of Ley, without, however, following him in his general conclusions, as that phase of the subject has not been studied in detail.

[2] K. C. Heald, "Contribution to the Geology of Western Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 8 (1924), pp. 242–43.

2

A REVIEW OF THE OIL AND GAS PROSPECTS OF AUSTRALIA[1]

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ABSTRACT

A comprehensive study of the literature and available data relative to the oil and gas prospects of Australia is made herein as a supplement to explorations of the writer in certain parts of that continent. Readers should bear in mind that Australia covers approximately the same area as the United States, consequently generalizations for the entire continent are difficult. Vast areas have been eliminated from consideration on account of remote age, metamorphism, or other factors. Other great regions have been eliminated on the basis of explorations by the writer and other geologists in search of oil. As a general statement, Western Australia and Tasmania are considered almost entirely unfavorable; South Australia and Victoria appear to be largely so; but a possibility of oil or gas may exist somewhere in New South Wales or Queensland.

No detailed structural surveys are known to have been made in Australia. The work has been entirely of a *reconnaissance* nature, except where areal mapping in some detail has been done with reference to coal and metal mining. Excellent geological work has been done by Australian geologists. The lack of positive information with reference to petroliferous conditions is mainly due, therefore, to lack of seepages and other surface indications, scarcity of obvious structures in suitable stratigraphic localities, and a considerable neglect of the studies of fundamental conditions relative to petroleum occurrence. The present paper does not pretend to be an exposition of the subject, but is merely a review of the available knowledge, calling attention to areas and fundamental conditions believed to be important in a broad consideration of oil prospects.

INTRODUCTION

Until 1923 comparatively little scientific thought was given the question of the presence or absence of oil in Australia. Although it had occupied the attention of newspapers, technical journals, certain state geologists, and the public for a decade or two, the oil fraternity had paid very little attention to the subject. A few widely scattered borings, sunk for oil to depths ranging from 100 feet to nearly 4,500 feet, had never discovered more than a few drops. In addition, thousands of artesian water wells throughout the continent had failed to strike oil, and only a small number of them encountered as much as 10,000 cubic feet a day of natural gas.

A few keen-visioned Australian business men and geologists were not satisfied with the quality of the negative evidence or with the lack of definite knowledge in several large basins of Permo-Carboniferous and later ages. The writer was accordingly called to Australia in the employ of Mr. Albert Edward Broué, of Sydney, in order to render a technical opinion of oil prospects in certain regions. The studies covered mainly large areas in western Australia, but they also extended into South Australia, Victoria, and New Zealand. Aside from personal observa-

[1] Manuscript received by the editor October 2, 1926.

[2] Consulting geologist and petroleum engineer.

tions published with the permission of his client, the writer has drawn freely on all published material which might help in the search for oil. He wishes to express his appreciation of numerous courtesies extended by his clients, as well as for valuable information and advice given by such scientific men as Professor Sir T. W. Edgeworth David, E. C. Andrews, A. Gibb Maitland, L. Keith Ward, W. Baragwanath, Leo Jones, and others.

Excellent geologic work has been done in Australia by government and private geologists, but with few intensive oil studies. A general warning had been given by Benfield,[1] but the first technical paper dealing with oil prospects of the continent as a whole was written by Andrews,[2] who concluded that the "geological history of Australia suggests decidedly that the conditions which controlled the formation of commercial oil pools of Tertiary age in the principal fields of the world, namely, those paralleling the curves, arcs, or zones of the Tethyan, Malayan, Antillean and Pacific, and the Alpine and similar mountain zones, did not extend to Australia." Andrews added that "if crude oil fields of commercial value do exist in Australia, they apparently belong to formations older than Tertiary."

Since the visit of the writer to Australia, some voluminous literature on Australian oil prospects has been produced by Wade,[3] in the employ of the Commonwealth government, and his work will be referred to frequently herein.

An account of oil prospects in New South Wales has been given by Jones.[4] More recently Skeats,[5] in a presidential address on some applications of geology to mining, delivered in 1925 before the Australian Institute of Mining and Metallurgy, gave a résumé of Australian oil possibilities from the geologic point of view. The oil prospects in South Australia have been set forth by Wade,[6] and those of

[1] B. Benfield, "Some Precautionary Suggestions on the Search for Oil in Australia and the Regions of the Pacific Basin," *Proceedings Pan-Pacific Scientific Congress*, 1923. 1276 pages.

[2] E. C. Andrews, "Prospects for Petroleum in Australia," *Economic Geology*, Vol. 19, No. 2 (1924), pp. 157–68.

[3] Arthur Wade, *Petroleum Prospects, Kimberley District of Western Australia and Northern Territory*. Printed in order of the Seattle, Melbourne, October 8, 1924. 63 pages, 13 plates and maps.

The Possibility of Oil Discovery in Queensland. Printed for the government, Melbourne, 1925. 31 pages, 8 figs.

Petroleum: Report on Investigations Made in New South Wales. Printed by authority, Melbourne, June 30, 1925. 18 pages, 1 map, and 2 plates.

"Report on Petroleum Prospects in Parts of Western Victoria, South Australia, and Western Australia," *Commonwealth Government Parliamentary Paper*, Melbourne, 1926. 4 pages.

"The Search for Oil in Australia," *Journal Institute Petroleum Technologists*, Vol. 12, No. 55 (April, 1926), pp. 145–64.

[4] Leo J. Jones, "Notes on Petroleum and Natural Gas and the Possibilities of Their Occurrence in New South Wales," *N.S.W. Department of Mines, Geol. Survey, Min. Res. No. 31*, 1921. 48 pages, 7 figs.

[5] Ernest W. Skeats, *Mining Magazine* (May, 1925), pp. 312–14.

[6] Arthur Wade, "The Supposed Oil-Bearing Areas of South Australia," *S.A. Department of Mines, Bulletin No. 4*, 1915. 53 pages, 23 illus.

Tasmania, by Twelvetrees.[1] Fairly comprehensive papers on Queensland and Northern Territory have been written by Jensen.[2] A recent paper by the writer deals with Western Australia.[3] Sundry articles on other states have appeared under different authorships. The present paper is intended merely to give a summary of existing knowledge on oil prospects in Australia as a whole, and should not be taken as a final exposition of the subject in regions not visited by the writer.

GENERAL PHYSICAL AND TECTONIC FACTORS

Australia is a continent about the size of the United States, excluding Alaska. The chief industries of Australia are sheep- and cattle-raising, agriculture, and mining. Although in general not mountainous, it has some important mountain ranges. In the middle of the continent, extending west to the Indian Ocean and south to the Antarctic Ocean, are great deserts, largely uninhabited and rarely traversed by white men. The climate ranges from intensely tropical in northern Queensland, Northern Territory, and Western Australia to mildly temperate in Tasmania. The rainfall varies from less than 10 inches per annum in the desert regions to more than 60 inches in western Tasmania, the extreme north of Northern Territory, a narrow belt along the coast of Queensland, and some spots in eastern New South Wales and Victoria, and is occasionally over 100 inches.

Previous investigators have postulated "arcs,"[4] or "festoons"[5] in the southwestern Pacific Ocean region to explain certain trend lines (mountain, fault, and formation strikes) that are prominent in a geological consideration of the islands. Marshall[6] has shown that the true tectonic margin of the southwestern Pacific Ocean coincides roughly with the outer zone of what Suess calls his "First Australian arc," which includes New Zealand, Loyalty Islands, and New Guinea, some of which are oil-bearing. This belt has been intensely affected by Mesozoic and Cenozoic movements.

At the other tectonic extreme the greater part of Western Australia and Northern Territory and vast regions elsewhere in Australia comprise a great massif of Archean and ancient Paleozoic metamorphic rocks, which constituted a land mass from Cambrian to Recent times, but against which successive sea invasions have deposited Paleozoic, Mesozoic, and Cenozoic sediments in encroaching "basins."

[1] W. H. Twelvetrees, "The Search for Petroleum in Tasmania," *Tasmania Mines Dept., Circular No. 2*, 1917. 18 pages.

[2] H. I. Jensen, "The Probable Oil Formations of Northeastern Australia," *Proc. Pan-Pacific Scientific Congress*, pp. 1254–76, 1923.

"Oil Possibilities in Queensland," *Queensland Government Mining Journal* (January 15, 1926), pp. 12–19; February 15, 1926, pp. 48–52.

[3] F. G. Clapp, "The Oil Problem in Western Austrialia," *Econ. Geol.*, Vol. 21, No. 5 (1926), pp. 409–30.

[4] Edward Suess, *The Face of the Earth*, Vol. 4 (1909), p. 301.

[5] J. W. Gregory, *Geography: Structural, Physical, and Comparative* (1908), p. 275.

[6] P. Marshall, "Presidential Address to Section C," *Australasian Assoc. for Advancement of Science*, Vol. 13 (1911), pp. 90–99, Plate 1.

In harmony with those in the Pacific area, the tectonic trends in the pre-Paleozoic and early Paleozoic rocks of northern Australia run practically east and west. Those adjoining the Coral Sea in northeast Queensland follow a northwest-southeast line, veering to the south in southeast Queensland. The structural trends in Paleozoic and Mesozoic rocks in New South Wales are practically north and south, as are those in extreme eastern Victoria and Tasmania.

GENERAL STRATIGRAPHY

Australia contains the great systems of rocks known elsewhere in the world, and many subdivisions of them. About a third of the continent consists at the surface of rocks of probable pre-Cambrian age, which include vast parts of the interior of Northern Territory and Western Australia, as well as many areas in New South Wales, Queensland, and Victoria. The pre-Cambrian rocks are so complex and widely distributed as to defy description in a single brief paper.

Some large areas of flat-lying Cambrian rocks exist in Northern Territory. The region known as the "Kimberleys," lying north of Desert Basin in Western Australia, as well as large areas in the northern part of Northern Territory, are occupied largely by granitic and metamorphic rocks overlain by a probable pre-Cambrian sedimentary series, some Cambrian rocks, and large areas of basalt.

In Australia the marine Tertiary strata are mainly limited to narrow coastal belts in Victoria, South Australia, and Western Australia, and fresh-water Tertiaries are confined to the Great Artesian Basin. Late Tertiary movements in Australia were mainly those of faulting, elevation of plateaus, and down-warping, with important igneous intrusions in several states. The maximum thickness of Tertiary beds proved by borings may be about 2,000 feet.

Excellent summaries of the known geology of several states[1] have appeared. Considering the continent as a whole, the geologic column given on page 55 (Table I) has been worked out.[2]

AREAS FOR CONSIDERATION

Areas in which the occurrence of oil or gas in commercial quantities may be ruled safely out of consideration because of antiquity, regional metamorphism, or obvious conditions have been eliminated, and those here listed (Table II) are

[1] Robert L. Jack and Robert Etheridge, Jr., *The Geology and Paleontology of Queensland and New Guinea*, Brisbane and London, 1892. 768 pages, volume of 68 plates, and geological map of Queensland (in 3 vols.).

C. A. Süssmilch, *An Introduction to the Geology of New South Wales*, Sydney, 1911. 177 pages, 79 illus.

Walter Howchin, *The Geology of South Australia*, Adelaide, 1918. 542 pages, illus.

A. Gibb Maitland, "A Summary of the Geology of Western Australia," *Mining Handbook, Geol. Survey Memoir No. 1*, chap. i, 1919. 55 pages, 1 map, and 80 figs.

[2] Simplified and amplified from that tabulated by Professor Sir T. W. Edgeworth David, *Federal Handbook* (1914), pp. 255–59, prepared in connection with the eighty-fourth meeting of the British Association for the Advancement of Science, held in Australia, August, 1914, pp. 241–325, 8 illus.

TABLE I

GENERALIZED GEOLOGIC COLUMN FOR AUSTRALIA (AFTER DAVID, MODIFIED)

System	Period	Maximum Thickness (Feet)	Description
Cenozoic	Recent	0–1,000	Alluvium, sand dunes, marshes, raised beaches, submerged peat beds, aboriginal kitchen-middens, laterites, salt flats, recent craters of Mount Gambier (S. A.) and Tower Hill near Warrnambool (Vic.), and the Great Barrier Reef of Queensland
			Helicidae sandstone of Bass Strait Islands and *Helicidae* limestone west of Cloncurry (Q.)
	Recent or Pleistocene	....	Mammaliferous drifts and old fossiliferous lake muds; glacial deposits of Western Tasmania and Kosciusko plateau (N. S. W. and Vic.)
		300	Basalts in Victoria and Tasmania, Kangaroo Id. (S. A.), and Bunbury (W. A.)
	Pliocene	....	Some newer deep "leads" of alluvial gold and tin in eastern Australia and Tasmania
	Lower Pliocene or Upper Miocene	1,000	Older Pliocene of Adelaide (S. A.), possibly Launceston (Tas.) lake beds, Port Moresby radiolarian cherts.
		2,000	Alkaline lavas and tuffs from Colcraine to Springsure (about 1,500 miles); melilite and nepheline basalts of Tasmania.
		100(?)	*Ostrea sturti* beds of lower Murray River and *Lithuthamnion* limestone of Hallett's Cove (S. A.)
	Miocene	80–1,000	*Cellepora gambierensis* limestones bordering Great Australian Bight
		500+	Leucitite plugs of Desert Basin (W. A.)
		200–1,500+	Older basalts, tuffs, and older "deep leads" of Gippsland (Vic.), New South Wales, and southern Queensland; much laterite and some bauxite
		0–900	Brown coal series of Victoria
	Oligocene	1,000+	Foraminiferal limestones of Cape Range and other parts of West Australian coast
Mesozoic	Upper Cretaceous	100–300	Some of the "desert sandstones" of generally fresh-water origin, passing downward into radiolarian shales and *Belemnites;* but in places marine, with *Rhynchonella croydonensis. Ichthyosaurus* occurs in an opal bed of this series

TABLE I—*Continued*

System	Period	Maximum Thickness (Feet)	Description
Mesozoic *Continued*	Lower Cretaceous	50+	Some tillites of Western Australia
		2,000	Rolling Downs formation, chiefly glauconitic sands and clays, with plentiful Foraminifera; Burrum coal seams of Queensland
	Upper Jurassic	500–1,000	Diabase sills of Tasmania
		1,000–3,000	Sandstones of Great Artesian Basin, with lignite in places; sandstones, limestone, and chalky beds of western Desert Basin and Northwest Basin (W. A.); coal measures of Wonthaggi, Cape Otway, Clarence series, Clifton, Ipswich, Callide, and Broadsound; quartz-trachyte tuffs of Brisbane (Q.); contains *Belemnites* and *Ammonites* in W. A.
	Triassic	3,000	Productive coal measures of Tasmania, some beds of Great Artesian Basin, Wianamatta shales, Hawkesbury sandstone series, and Narrabeen beds of Sydney Basin (N. S. W.), much red and green tuff at base of last named series; basalt intrusions in Sydney Basin
Paleozoic	Permo-Carboniferous	....	Acid granites of New England (N. S. W.); alkaline series of Port Cygnet (Tas.) and Kiama (N. S. W.)
		1,500	Upper or Newcastle coal series with Bulli coal seam at the top (N. S. W.); Upper Bowen coal measures of Queensland and Collie coal field of southwestern W. A.
		2,200	Dempsey series; barren fresh-water strata
		500–1,800	Middle coal measures (Tomago or East Maitland)
		6,400	"Upper Marine" series of N. S. W. and Queensland; mudstones and sandstones; tillites and glacial erratics in N. S. W.
		2,000–10,000	Thick sandstones of Desert and Northwest basins, W. A.
		100–300	Lower or Greta coal measures of N. S. W.; possibly minor coal beds of W. A.; probably Dawson coal measures of Queensland and Mersey coals of Tasmania
		4,800	"Lower Marine" series of N. S. W. and Queensland with interstratified basalts and tuffs; Bacchus Marsh beds of Victoria (2,000 ft.) with at least five beds of tillite (tillites correlated with Dwyka beds of South Africa, Talchir beds of India, Orleans conglomerate of South Brazil and Argentine); different tillites

TABLE I—*Continued*

System	Period	Thickness Maximum (Feet)	Description
	Permo-Carboniferous *Continued*		of N. S. W. (300 ft.), Wynyard (Tas.), and Hallett's Cove (S. A.), the last resting on a striated pavement
		100+	Gympie beds of Queensland; Lyons conglomerate (tillite) of W. A.
	Unconformity		
	Carboniferous	....	Sphene-granites and blue-granites of New England (N. S. W.)
		1,000–20,000	"Star series" of Queensland; marine and fresh-water beds in N. S. W.; marine beds of W. A.; thick series of acid to intermediate lavas and tuffs; sandstones of Mansfield beds (Vic.); felsites and basalts of Mount Wellington (Vic.)
		....	Serpentine belt of New England (N. S. W.)
Paleozoic *Continued*	Upper Devonian	10,000	*Spirifera disjuncta* quartzites of Mount Lambie (N. S. W.); and perhaps the *Archaeopterix* sandstones of Victoria
	Middle Devonian	9,000	Radiolarian cherts, reef limestones, and spilites of Tamworth (N. S. W.); Burdekin series of Queensland with reef limestones as much as 7,000 feet thick (an ancestor of the Great Barrier Reef); Buchan and Bindi limestones of Victoria, with andesites; Devonian rocks on north edge of the Desert Basin (W. A.)
	Lower Devonian	14,000	Murribidgee series and a thick series of acid to intermediate lavas (N. S. W.); series of acid lavas and tuffs and Snowy River porphyries (Vic.); dacites, quartz-porphyries, and granodiorites of Victoria; probably most of the granites of Tasmania
	Silurian	3,000–5,000	Shales, sandstones, limestones, and contemporaneous tuffs of which the type area is Yass (N. S. W.); limestone at Lilydale (Vic.), Chudleigh (Tas.), and Chillagoe (Q.), frequently associated with radiolarian cherts
	Unconformity		
	Ordovician	9,000(?)	Littoral beds (as Tempe Downs beds, south of the MacDonnell Range, N. Ter.) or black shales, sandstones, graptolitic and phosphatic shales with cherts (as in Victoria, also developed at Tallong and Mandurama (N. S. W.)

TABLE I—*Continued*

System	Period	Maximum Thickness (Feet)	Description
Paleozoic *Continued*	Cambro-Ordovician (?)	....	Diabases and tuffs, probably spilitic, of Heathcote (Vic.); probably the porphyroid series with breccias and tuffs of western Tasmania
	Cambrian	0–10,000 (?)	Chiefly developed in S. A. and Northern Ter. In N. Ter. thick sandstones overlie massive *Archaocyathinae* limestones—"another forerunner of the Great Barrier Reef," a vast thickness of basalts and basic tuffs beneath richly fossiliferous (*Salterella*) limestone of N. Ter., tillites 1,000 ft. thick in middle of series in S. A.; probably Nullagine series of W. A. in part
Great Unconformity			
Pre-Cambrian	Algonkian	?	The shistose Mosquito Creek series of Pilbara Goldfield (W. A.)
		?	Warrawoona sedimentary series of W. A.
		?	Conglomerates of the Kalgoorlie Goldfield (W. A.) and Goat Is. (Tas.), with mica schists and garnet-zoizite-amphibolites; rocks of the Houghton magma in Mount Lofty and Flinders Ranges (S. A.)
		?	Probably the Glenelg River schists and Mitta Mitta schists of Victoria and mica-schists and quartz schists of N. Ter.
	Archean	....	Archean rocks of Musgrave and MacDonnell Ranges (W. A.), Port Lincoln (S. A.), and between Camooweal and Borraloola (N. Ter.); possibly the glaucophane schists of the Aguilar Range (Q.)

provisionally outlined as worthy of discussion from the standpoint either of further attention or immediate elimination. It is intended that this list include all areas that scientific men have ever considered seriously with reference to oil. In the artesian basins here scheduled (areas 1 to 9) the borders as generally mapped have been expanded to include any formations in which oil prospects might seem to geologists to be worthy of discussion after the broad eliminations rendered possible under general "Stratigraphy" and "Tectonics."

These areas will be discussed one by one, commencing with the several artesian basins.[1]

[1] Reports of First, Second, Third, and Fourth Interstate Conferences on Artesian Waters.

1. GREAT ARTESIAN BASIN

The largest artesian-water area in the country is known as the Great Artesian Basin, and includes more than half the state of Queensland, the northeastern quarter of South Australia, the central-northern and northwestern parts of New South Wales, and the southeast corner of Northern Territory. The area of this great basin, including pertinent outcrops, is estimated as 475,000 square miles. It consists mainly of Permo-Carboniferous, Jurassic, Cretaceous, and Tertiary

TABLE II

AREAS CONSIDERED IN THIS PAPER

Number on Map	Name of Area	States
1.....	Great Artesian Basin	Q., N. S. W., S. A., and N. Ter.
2.....	Desert Basin	W. A. and N. Ter.
3.....	Murray River Basin	S. A., Vic., and N. S. W.
4.....	Eucla Basin	W. A. and S. A.
5.....	Northwest Basin	W. A.
6.....	Coastal Plain Basin of Western Australia	W. A.
7.....	Gulf Basin	W. A. and N. Ter.
8.....	Ord River Basin	W. A. and N. Ter.
9.....	Victoria coastal area	Vic.
10.....	Sydney Basin	N. S. W.
11.....	Eastern Queensland Permo-Mesozoic areas	Q.
12.....	Western part of Cape York peninsula	Q.
13.....	Grafton Basin	N. S. W.
14.....	Tasmania areas	Tas.
15.....	Kangaroo Island and adjoining coasts	S. A.
16.....	Brisbane coastal belt	Q.
17.....	Region between Great Artesian Basin and Eucla Basin	S. A. and W. A.
18.....	Elcho Island and Waggon Lagoon	N. Ter.

sediments, of which the Tertiary and late Cretaceous strata are of fresh-water origin. Table III shows a generalized section.

Flows of artesian water ranging from a few thousand to 3,630,000 gallons a day are derived from porous sandstones of Triassic and Jurassic ages in wells ranging from 1,000 to 7,000 feet deep. The country is difficult to decipher geologically, little folding is revealed by *reconnaissance* field work, and horizons have not been successfully correlated between wells. The normal dip is about 40 feet per mile toward the center of the basin. Jensen[1] claims that "broad and gentle" domelike folds exist near the margins of the basin in Queensland, and that oil will be found in them. Controverting the general supposition that the beds are all of fresh-water origin, in which most geologists hesitate to concede a possibility of oil occurrence, he states that "the Cretaceo-Tertiary beds unconformably overlie the Cretaceous marine and Jurassic beds on the western edge of the basin." He believes the area is a "sealed" basin, from which oil cannot escape as seepages owing to certain paleographic and physiographic causes, and that "the upper Jurassic

[1] H. I. Jensen, "The Probable Oil Formations of Northeastern Australia," *Proc. Pan-Pacific Scientific Congress*, pp. 1254–76, 1923.

artesian beds and the Cretaceous subartesian beds, waterlogged and saturated, form an effectual seal for the oil stored in the Lower Jurassic." Jensen claims that two formations "possess to a marked degree the characters requisite for an oil-bearing series, namely, the Lower Walloon formation of southern Queensland and the Upper Permo-Carboniferous in northwestern Queensland and in the Northern Territory as well." He states that the monocline, dipping toward the center of the basin, is "corrugated with superimposed anticlines of a gentle nature"; but he

TABLE III

GEOLOGIC COLUMN OF GREAT ARTESIAN BASIN

Period	Formation or Series	Maximum Thickness (Feet)	Description
Cretaceo-Tertiary	"Desert sandstone"	300+	Fresh-water sandstones and mudstones
	Uniformity		
Lower (or Marine) Cretaceous	Rolling Downs	2,000	Calcareous mudstones
	Slight Uniformity		
Upper, Middle, and Lower Jurassic	Upper Walloon	5,000	Red sandstones
	Middle Walloon		Characterized by much petrified wood, silicified and in part opalized
	Lower Walloon		Calcareous sandstones and shales, with many coal seams; lenses of conglomerate near the base
Triassic	Bundamba	250	Siliceous sandstones and some shale
	Ipswich	?	Sandstones, tuffaceous at top
	Unconformity		
Permo-Carboniferous	Upper and Middle Bowen	1,500	Sandstones, shales, and coals
Carboniferous	Lower Bowen	?	....

qualifies this statement by explaining that the most favorable corrugations show "merely as an arrest or increase of dip on the general slope of the monocline, producing terraces," which are the structures he believes favorable for oil. Reverse dips were seen by Wade, who believes sizable structures exist in the Roma region of southern Queensland. It is not apparent that any detailed mapping has been done.

Additional light on the relations between Permo-Carboniferous, Mesozoic, and later sediments in the southwest part of the Great Artesian Basin is given by Ward[1] and one of the most comprehensive treatises on the basin as a whole is by

[1] L. Keith Ward, *Transactions Royal Society of South Australia*, Vol. 49 (1925), pp. 61–84; 6 plates.

Pittman,[1] who appends a fifteen-page bibliography of Australian artesian waters. Several government reports[2] touch on the oil possibilities of this basin. Wade considers[3] that in southeastern Queensland "the only geological series with which we need to interest ourselves is the Walloon series," of Cretaceous age. These rocks are mostly sandstones, limestones, shales, coals, and "kerosene shales."[4]

Between 1897 and 1922 five wells were drilled[5] at Roma inside an area of less than two acres. One of these (No. 3), originally sunk for water, was deepened in 1900 and gas was discovered at a depth of 3,683 feet and allowed to escape for more than four years. In 1905 the town council installed a lighting system, the gas supply failed, and the well again came into use for water supply. Another well was commenced in 1907 by the Roma Mineral Oil Company, and in 1908 "wet" gas, estimated by J. B. Henderson, government analyst, as having a volume of 10,000,000 cubic feet a day and a pressure ranging from 200 to 300 pounds per square inch, was tapped at a depth of 3,702 feet. After this gas had burned about five weeks, drilling was continued, but was later abandoned. Another hole was drilled by the Queensland government in 1916, but was abandoned after an accident occurred 2,700 feet from the surface.

No surface structure is evident at Roma. The top of the Walloon series is believed to lie 300 feet from the surface, and the wells continued in this series

[1] E. F. Pittman, "The Great Artesian Basin and the Source of Its Water," *Dept. of Mines, Geol. Survey New South Wales*, 1914. 57 pages, plates and maps.

[2] The following are those which appear pertinent:

Author	Title	Publication
Anon	Roma Oil, Queensland	Q. Gov. Min. Jour. (January, 1905)
Anon	Roma Oil, Queensland	Q. Gov. Min. Jour. (November, 1908)
W. E. Cameron	The Search for Oil at Roma	Q. Gov. Min. Jour., Vol. 12 (October, 1911)
A. C. Veatch and others	Natural Gas and Petroleum—Report on the Roma District	Q. Gov. Min. Jour. (April, 1913)
L. C. Ball	Oil Shale in Central Queensland	Q. Gov. Min. Jour., Vol. 16 (September, 1915)
W. E. Cameron	Boring for Oil at Roma	Q. Gov. Min. Jour., Vol. 16 (November, 1915)
W. E. Cameron	Petroleum and Natural Gas Prospects at Roma	Q. Geol. Survey, Pub. 247, 1915
L. C. Ball	Lowmead No. 1 Bore and the Tertiary Oil Shales of Baffle Creek	Q. Gov. Min. Jour., Vol. 17 (January, 1916)
L. C. Ball	Oil Shales and Coal at Sugarloaf, on the Oakey-Cooyer Railway	Q. Gov. Min. Jour., Vol. 17 (April, 1916)
L. J. Jones	Petroleum and Natural Gas and Possibilities of Their Occurrence in New South Wales	N. S. W. Dept. of Mines, Geol. Survey, Min. Res. No. 31, 1921
H. I. Jensen	The Tambo and Barcaldine Districts: Oil Manifestations of the Enniskillen Range	Q. Gov. Min. Jour., Vol. 23 (April, 1922), p. 157
C. C. Morton	Occurrence of Petroleum on Nogoa Downs, Emerald District	Q. Gov. Min. Jour., Vol. 23 (June, 1922), p. 225
H. I. Jensen	The Oil Prospects of the Lower Walloon Strata of Western Queensland	Q. Gov. Min. Jour, Vol. 23 (June, 1922), p. 226
H. I. Jensen	Oil Prospects at Hutton Creek	Q. Gov. Min. Jour., Vol. 23 (June, 1922), p. 228
Anon	The Search for Oil: Activities at Roma and Beaudesert	Q. Gov. Min. Jour., Vol. 23 (November, 1922), p. 434
E. C. Saint-Smith	Boring for Oil at Wolston	Q. Gov. Min. Jour., Vol. 24 (February, 1923), p. 56
L. C. Ball	The Search for Oil—Samples from Orallo, Etc.	Q. Gov. Min. Jour., Vol. 25 (March, 1924), p. 95

[3] Arthur Wade, *The Possibility of Oil Discovery in Queensland*. Printed for the government of Australia, 1925, p. 17.

[4] H. I. Jensen, *Proceedings Linn. Soc. New South Wales*, Vol. 47, Part 2 (1923), pp. 153–58.

[5] W. E. Cameron *et al.*, "Petroleum and Natural Gas Prospects at Roma," *Queensland Geol. Survey Publication No. 247*, 1915.

from that depth downward. A yield of 1.2 pints of gasoline per 1,000 cubic feet of gas was obtained, of which the following is an analysis:

ANALYSIS OF GAS FROM ROMA, QUEENSLAND*

Kind of Gas	Percentage
Paraffin series (including ethane, 9.8 per cent)	82.4
Benzine series	5.0
Olefin series	1.5
Carbon monoxide	5.8
Carbon dioxide	1.5
Nitrogen and residual gas	3.4
Oxygen and hydrogen	0.0
Total	99.6

*Cameron, *op. cit.*, p. 33.

No oil was found in this well; but Jensen states that the "survey of the country north of Roma proved the existence of three horizons of Walloon coal measures, two of which only have been pierced by the Roma bore," so that oil possibilities may exist below.

At Orallo, north of Roma, two holes were drilled; the first was 2,233 feet deep, and the second reported more than 2,500 feet. The operations were shrouded in mystery and contending arguments; both wells were abandoned as dry; and it seems probable that only minute showings of oil were found, if indeed the oil reported did not come from the drilling machinery.

At Ruthven an artesian well 4,105 feet deep flows very slightly saline hot water which has a temperature of 190° F. and carries on its surface "a thick, dark, oily film which looked like a dark-brown crude liquid petroleum,"[1] classed by the government analyst as ozokerite. A map by Ball[2] gives localities of small oil showings in several wells drilled in Queensland for water and coal. Evidences are mapped by Ball or described by him or by Jensen[3] at Springleigh, Julia Creek, Ensay, Mingeburra, Thornleigh, Bimerah, Macfarlane, Minnie Downs, Malta, Bogarella, Ruthven, Lucknow, Warbreccah, and Thomson Watershed. These "indications" are "oil fractions," "black, tarry oil," or "a little paraffin wax," which rise with the artesian water, always in minute quantities. Localities of gas occurrence are mapped by Ball at Lucknow, Glenariffe, Evesham, Manfred, Brookwood, Janesland, Bedourie Station, Forest, Thomson Wells, Tocal, Warbreccah, Bimerah, Medlew, Home Creek, Danderaga, Avoca, Mount Hutton, Wood-duck, Landler, Counda, Scouller, and Dalby. Jensen states that although the age of beds carrying oil is in most cases problematical, it is in every case below the artesian water beds.

[1] Arthur Wade, *op. cit.*, p 25.

[2] Lionel C. Ball, *Queensland Government Mining Journal*, June, 1922.

[3] H. I. Jensen, "The Probable Oil Formations of Northeastern Australia," *Proc. Pan-Pacific Scientific Congress*, pp. 1257–58, 1923.

In the New South Wales part of the Great Artesian Basin only a trace[1] of oil was found in probable Mesozoic rocks in a well 700 feet deep at Coonamble, 220 miles northwest of Sydney. Gas examined from artesian wells in the New South Wales part of the basin does not appear to be "wet gas."

The basin has been studied in great detail by Australian geologists because of its water problems, and few signs of petroleum are likely to have been neglected. A fair summary of the chances of finding oil in this basin in Queensland has been made by Wade,[2] who considers that "there is hope of oil being present at moderate

FIG. 1.—Map of Australia showing areas referred to in this paper (numbers coincide with those used in the text).

depths, where structural features are favorable," and that "the evidences are good enough to encourage further prospecting work." He emphasizes the need for detailed work on structural geology before suitable locations can be selected. He states that the necessary prospecting is "not work for small companies of limited means," but is the sort "which only a large corporation having ample reserves of capital specially earmarked for such a purpose could seriously undertake"; that attention to the search for oil should "be encouraged by the granting of large areas for prospecting and for subsequent development"; and he suggests some changes in the state mining regulations to secure this effect.

[1] E. C. Andrews, *Econ. Geol.*, Vol. 19, No. 2 (1924), p. 161.

[2] *Op. cit.*, pp. 29–30.

2. DESERT BASIN

Although Desert Basin and pertinent outcrops of its formations cover an area of approximately 165,000 square miles in the northern part of Western Australia, none but water wells have been successful in it. The deepest of these are in the vicinity of Broome and Derby in the northwest corner of the basin. Only three or four are deep artesian wells, the absence of others doubtless being due to the fact that the country is mainly an uninhabited desert.[1] Artesian flows may not be obtainable commensurate in size with those of the Great Australian and Northwest basins, since the strata of Desert Basin consist of many thousand feet of sandstones without apparent shale capping.

The oil possibilities of Desert Basin have been discussed briefly by the writer;[2] a paper describing them in some detail in now in press,[3] and the oil prospects of the northern or Fitzroy River part of the basin were studied by Wade.[4] The strata range in age from Carboniferous to Jurassic, with fringes and isolated areas of Tertiary age. Porous sandstones exist, adequate to hold oil, but no shales of importance are known, and cover rocks are largely missing. Suitable structures are known in the northern part of the basin near Fitzroy River and its tributaries, Christmas and Price's creeks, but drilling upon them has only resulted in finding traces of bituminous material at depths of 109 and 121 feet at Mount Wynne, and possibly small oil showings 1,000 feet deep in Price's Creek dome.

The Mount Wynne test hole is said to have been nearly 2,000 feet deep when completed, the four Price's Creek borings ranged from 444 to 1,008 feet deep, and Wade states[5] that "it is now thought that the chances of success may be greater at Pool Range," where "the structure is that of an elongated dome, the axis of which is broken by trough faulting." At Broome two artesian water wells were drilled 1,459 and 1,775 feet deep and two such wells in the vicinity of Derby were 900 and 3,012 feet deep.

Near Mount Wynne a hot spring discharges 80,000 gallons of water a day, through which some hydrogen sulphide gas escapes. None of the several wells as deep as 100 feet drilled on the coast from Derby southwest to Port Hedland has resulted in a known trace of oil or gas. Seepages appear not to exist. In fact, nothing favorable could be found in the geology of Desert Basin aside from anticlinal structures, and in these the rocks may be too greatly metamorphosed to carry commercial oil. The rocks of Fitzroy Valley are intruded by a number of leucitite plugs of probable Tertiary age.

[1] F. G. Clapp, "A Few Observations on the Geology and Geography of Northwest and Desert Basis, Western Australia," *Proceedings Linn. Soc. New South Wales*, Vol. 50, Part 2 (1925), pp. 47–66, plates 16–19.

[2] *Econ. Geol.*, Vol. 21, No. 5 (1926), pp. 412–16.

[3] F. G. Clapp, "Oil Prospects of the Desert Basin of Western Australia," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 11 (November, 1926), pp. 1118–35

[4] Arthur Wade, *Petroleum Prospects, Kimberley District of Western Australia and Northern Territory.* Printed by order of the Senate, Melbourne (October 8, 1924), pp. 10–26.

[5] *Jour. Inst. Petrol. Tech.*, Vol. 12, No. 55 (April, 1926), p. 151.

3. MURRAY RIVER BASIN

Murray River Basin is a large artesian area in southwestern New South Wales, southwestern South Australia, and western and northwestern Victoria, whose pertinent outcrops comprise about 130,000 square miles. As in the Great Artesian Basin, so also in Murray River Basin, a large number of artesian wells have been drilled, and immense volumes of water obtained from depths ranging from a few feet to more than 1,000 feet, but only small showings of gas have been found, and oil is not reported. The formations are believed to be mainly of Tertiary and Recent ages, but some Jurassic areas exist. Some structures near the boundary between South Australia and Victoria, in the general vicinity of the Antarctic Ocean, have been discussed by Wade,[1] who considers some of them ancient dunes, but states that true folding does exist near the border. At Mount Gambier the sediments are intruded by basalts. The basin rocks have been penetrated without results by coastal borings to depths of several thousand feet. At Tailem Bend, Ki Ki, Coonalpyn, and Cooks Plains igneous rocks were encountered a few hundred feet from the surface.

In 1924 at least a dozen companies were holders of licenses to search for oil in South Australia, having properties throughout the Coorong and the west coast of Eyres Peninsula. At Robe a hole was drilled to a depth of 4,504 feet, and other fairly deep borings for oil were made at Tantanoola (1,165 ft.), Kingston (1,160 ft.), and Blackford (1,360 ft.). A boring on Glenelg River entered quartzite at 1,554 feet. In discussing the Glenelg area, Wade states[2] that "nobody can say that it is not possibly oil-bearing," that "it is possible that suitable structural conditions exist"; but that "except for one very doubtful seepage in the gorge of the Glenelg River, on the Victorian border, where the best exposures of the Tertiary strata are to be seen, no oil-bearing stratum has been observed."

There are small artesian areas outside Murray River Basin in the vicinity of Spencer Gulf and Gulf of St. Vincent, but their total area is hardly 2,000 square miles. Along the coast about 90 miles southeast from the mouth of Murray River extends a narrow coastal lake known as the Coorong, and in this vicinity many "oil indications" have been alleged from time to time. The so-called "coorongite," which comes mainly from this region, is shown on a later page to be a product of vegetable growth.

4. EUCLA BASIN

The name "Eucla Basin" is given to an area of some 80,000 square miles in southeastern Western Australia and southwestern South Australia bordering on the Great Australian Bight. In this basin artesian flows, ranging from a few thousand to 250,000 gallons of water a day are produced from wells whose depths range from a few hundred to more than 2,000 feet. A large part of the basin consists of the Nullabor plains, on which the Trans-Continental Railway runs straight a

[1] "Report on Petroleum Prospects in Parts of Western Victoria, South Australia, and Western Australia," *Commonwealth Government Parliamentary Paper*, Melbourne, 1926. 4 pages.

[2] *Jour. Inst. Petrol. Tech.*, Vol. 12, No. 55 (April, 1926), p. 151.

distance of 400 miles, with no deviation and no visible tree or surface undulation. The oil prospects have been discussed by Gibb Maitland[1] and lately summarized by the writer.[2]

The strata of Eucla Basin are of Cretaceous and Tertiary ages. The former crop out only far north of the Trans-Continental Railway, but the Nullabor plains consist of southward-dipping Tertiary limestones in which no folding is known. Some artesian waters on the border between South Australia and Western Australia are strongly saline,[3] but no trace of oil or gas has been reported and no abnormal structure is known. Nothing observed in this basin is considered favorable to oil occurrence.

5. NORTHWEST BASIN

The geology[3] and oil prospects[4] of Northwest Basin have been discussed briefly by the writer, and in greater detail in a paper now in press.[5] This basin, which, with its pertinent outcrops, is estimated as 45,000 square miles in area, borders Indian Ocean from the vicinity of Onslow southward almost to Geraldton, and includes the town of Carnarvon and a small village called Gascoyne Junction. To the south the basin is practically continuous with Coastal Plain Basin, but is separated from it by the "Northampton Mineral Area" north of Geraldton.

The geology of Northwest Basin is similar to that of Desert Basin. In fact, fundamental conditions are such that rocks of the two basins were doubtless once connected, either across the intervening 400 miles of Cambrian and pre-Cambrian plateaus, or beneath the Indian Ocean. The strata range in age from Carboniferous to Tertiary. Some anticlines have been observed in the eastern part of the basin and also in Oligocene strata of the coast; but, aside from structure, nothing was found which might be considered favorable to oil occurrence. The Carboniferous and Jurassic rocks are not believed to contain shales or other beds suitable for cover to the vast thickness of sandstones, and foraminiferal Oligocene limestones of the coast do not appear to have an impervious cover. Moreover, the two score, more or less, of artesian wells ranging from a few hundred to more than 3,000 feet deep throughout the basin—some of which have individual flows up to 2,000,000 gallons of water a day—give no indication of the presence of oil, and such minute gas occurrences as are reported could not be verified by eye examination or attempted ignition. This basin is considered unfavorable to commercial oil occurrence.

[1] A. Gibb Maitland, *Petroleum Prospects of the Nullabor Plains, Eucla Division.* Printed by authority, Perth, 1919.

[2] *Econ. Geol.*, Vol. 21, No. 5, pp. 426–28.

[3] *Proceedings Linnaen Soc. New South Wales*, Vol. 50, Part 2 (1925), pp. 47–66, Plates 16–19.

[4] *Economic Geology*, Vol. 21, No. 5 (1926), pp. 418–21.

[5] "Oil Prospects of the Northwest Basin of Western Australia," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 11 (November, 1926), pp. 1136–49.

6. COASTAL PLAIN BASIN OF WESTERN AUSTRALIA

Although all artesian water basins in Western Australia touch the coast, the one known to Westralian geologists as the Coastal Plain Basin, about 15,000 square miles in area, commences north of Geraldton and extends south of Cape Naturaliste, a distance of more than 350 miles, and its greatest breadth east and west is as much as 70 miles.

The oil prospects of this basin have been discussed briefly by the writer.[1] The formations range in age from Carboniferous to Tertiary, and are in general a series similar to those in Northwest and Desert basins, with which the Coastal Plain Basin was doubtless once connected, for it is barely separated from Northwest Basin by the "Northampton Mineral Area" north of Geraldton. Northwest Basin includes the thriving city of Perth, capital of Western Australia, its widespread suburbs, the city of Geraldton, and many towns. It is the most populous and best known geologically of any basin in Western Australia.

Unlike Northwest and Desert basins, however, Coastal Plain Basin has notable shale beds and some Permo-Carboniferous coals. The Permo-Carboniferous strata are divided into an Upper and a Lower series, of which the Lower is believed to consist predominantly of limestone, and the Upper predominantly of sandstone, the total thickness of which is unrecorded and may amount to only a few hundred feet. The greater part of the basin, however, is covered with Jurassic rocks, which may be in places 3,000 feet thick, above which 1,000 feet or more of Cretaceous beds, which seldom crop out, may occur locally. The strata dip to the west with few known interruptions, but at least one prominent fold is known on Irwin River, 50 miles southeast of Geraldton. The Permo-Carboniferous beds are here folded into the broad Dongara anticline[2] surrounded by overlying Jurassic rocks. Other anticlines may exist, but they have not been discovered.

Owing to geologic structure and presence of known shales, the Coastal Plain Basin may be considered the least unfavorable of any Westralian district. Nevertheless, none of the many borings for artesian water which have gone to depths ranging from a few hundred to 2,000 feet has reported any oil or gas, but, on the contrary, some of these wells have a daily yield ranging from 100,000 to 1,870,000 gallons of fresh water. No seepages or other indications of oil are known in the basin, and, everything considered, it is not believed to be favorable.

Some oil excitement has existed in the past in the Warren River district in the southeast corner of this basin southeast of Cape Naturaliste, where several wells were sunk and some oil was reported. One well passed out of Permo-Carboniferous beds into detrital granitic material at 1,719 feet; the reported "showings" are not believed to have been genuine, and the structural attitude of the strata appears

[1] *Econ. Geol.*, Vol. 21, No. 5 (1926), pp. 421–24.

[2] W. C. Campbell, "The Irwin River Coal Field and the Adjacent Districts from Arrino to Northampton," *Western Australia Geol. Survey Bull. 38*, 1910. 108 pages, 6 plates, 53 figs.

A. Gibb Maitland, "Mining Handbook," *Geol. Survey Memoir No. 1*, chap. i (1919), pp. 37–38 and illus.

unsuitable for oil occurrence. In the first official report on the Warren River area the government geologist declared that[1] "no petroleum has been discovered in the district"; that the structure appeared unfavorable; and all subsequent reports from official sources have been of similar tenor.[2] A paper on the vicinity of Wonnerup and Busselton, east of Cape Naturaliste, was also written by Gibb Maitland,[3] and a paper by De Courcy Clark[4] referred to the same locality, both geologists considering oil occurrence improbable.

7. GULF BASIN

In the northeast corner of Western Australia and the northwest corner of Northern Territory lies an area scarcely 25 miles wide, extending northeast about 200 miles, in which the strata are mapped as Permo-Carboniferous. As far as known, they dip seaward at slight angles, and nothing indicates any oil occurrence. Near Port Keats, 130 miles northeast of Wyndham, borings for coal reached a depth of 1,500 feet[5] and seem to have encountered a granitic floor. From 1897 to 1907 three diamond-drill holes were sunk at Wyndham to depths of 690, 1,337, and 203 feet, respectively; the first two failed to find water, but No. 3 reported an artesian flow of 700 gallons a minute. No traces of oil or gas were reported in any of them.

8. ORD RIVER BASIN

Ord River Basin, an elliptical area only about 80 miles long and 40 miles wide, through which flows Ord River, has been discussed by Wade.[6] It lies about 175 miles south of Wyndham, partly in Western Australia and partly in Northern Territory. All rocks of this basin, which are estimated as 8,000 feet thick, are believed to be of Cambrian and pre-Cambrian ages. They consist of quartzites, silicified limestones, conglomerates, sandstones, and visicular basalts, overlain by 1,700 feet or more of flaggy sandstones and limestones. The highly inclined basaltic rim of the basin dips inward from all directions, but the beds in the center are nearly flat.

Basalt comprises at least half the geologic column of Ord River Basin. A rather remarkable fact is the occurrence of solid hydrocarbons ("asphalt glance") in small quantities in two localities 5 miles apart, in vesicles, cracks, and pipes of doleritic basalt[7] in the north rim. One occurrence is near Texas Downs Homestead

[1] A. Gibb Maitland, "The Reported Petroliferous Deposits of the Warren and Donnelly Rivers," *Western Australia Geol. Survey, Ann. Rept.* (1902), 13 pages.

[2] H. P. Woodward, "The Reported Petroliferous Area of the Warren River District (Southwest Division)," *Western Australia Geol. Survey Bull. 65*, 1915, 54 pages and 2 maps.

[3] A. Gibb Maitland, *Petroleum Prospects of the Busselton Neighborhood, Southwest Division.* Printed by Authority, Perth, 1921.

[4] Edward de Courcy Clark, *The Reported Occurrence of Oil Near Wonnerup, Southwest Division.* Printed by Authority, Perth, 1916.

[5] H. I. Jensen, "The Northern Territory," *Proc. Roy. Geol. Soc. Australasia*, Vols. 32–33, p. 14.

[6] Arthur Wade, *Petroleum Prospects, Kimberley District of Western Australia and Northern Territory.* Printed by order of the Senate, Melbourne (October 8, 1924).

[7] D. J. Mahoney, in a private report to Okes-Durack Oil Company, 1923.

on Ord River and the other is at the junction of Ord and Negri rivers. Wade considers the asphaltum to be derived from the overlying Negri series of Upper Cambrian age, which is in places crowded with organic remains ample to provide a source, but furnishing no other indication of the presence of oil.

The remainder of the section is not perceptibly petroliferous. Suitable structures are not reported, and no seepage or oil sand was found by Wade anywhere in the 200 miles of outcrop surrounding this basin. A well which entered basalt at a depth of 1,196 feet met with no success. The dark shales and underlying massive quartzites are believed to be of the same age as those forming a wide area in the north part of Western Australia and Northern Territory, that is, lower Cambrian or Algonkian.

9. VICTORIA COASTAL AREA

The south coast of Victoria, with notable exceptions, from a point 130 miles west of Melbourne extending 200 miles east of that city, is an area of Pliocene, Pleistocene, and Recent sediments having a breadth of 10 to 40 miles, in which lie minor areas of ancient basalts and Jurassic, Eocene, and Miocene beds.

In 1924 a well was drilled to lower Paleozoic rocks at Lake Bunga, 4 miles east of Lakes Entrance and 1 mile from the sea, in southern Tambo County, 160 miles east of Melbourne. On October 23 of that year "dry" gas was reported bubbling through water from Tertiary beds at a depth of 1,070 feet, but members of the Victorian Geological Survey assured the writer that the volume was only about 100,000 cubic feet a week, analyzing 93.74 per cent methane and 5.12 per cent nitrogen. It is reported that tiny drops of oil rose through the water under great artesian head. Several wells were being drilled in 1924 in the southern part of the state, but none was supposed to be wisely located, even if the area itself had been favorable.

10. SYDNEY BASIN

In New South Wales the Triassic and Permo-Carboniferous rocks total about 20,000 feet in thickness and form a narrow belt from Jervis Bay north beyond Port Macquarie, expanding in the vicinity of Newcastle and Sydney into a basin extending about 120 miles northwest, almost connecting with the southeastern angle of the Great Artesian Basin. In eastern New South Wales Triassic rocks comprise an area commencing 20 miles from Jervis Bay and extending north within 10 miles of Newcastle; they also extend 90 miles northwest of Sydney, coinciding roughly with the physiographic basin of the same name. Thus the broader Sydney Basin, geologically considered, has an area of about 20,000 square miles. The sediments are subdivided as shown in Table IV.

Permo-Carboniferous beds are exposed only in about 1,000 square miles near Jervis Bay, in a large area north of Newcastle, and belts along the basin borders. The basin has been given consideration by Wade,[1] and an investigation of some areas was made in 1925 by C. W. Washburne, but the results of the last-mentioned

[1] Arthur Wade, *Petroleum: Report on Investigations Made in New South Wales.* Printed by Authority (Melbourne, 1925), pp. 7–15 and map.

work are not available for publication. The combined Triassic and Permo-Carboniferous rocks of Sydney Basin are folded into low domes and one prominent monocline, which maintain a north-south trend across the basin along the east flank of Blue Mountains. The known anticlines are faulted and intruded by igneous masses, and there appears to be a fair chance that some of the folds may be caused by masses of igneous rocks below the surface.

TABLE IV

GEOLOGIC COLUMN OF CENTRAL SYDNEY BASIN

Period	Series or Formation		Maximum Thickness (Feet)	Description
Triassic	Wianamatta shales		600	Black carbonaceous shales and sandy shales, with at least one coal bed
	Hawkesbury sandstone		1,200	Massive sandstone with some shales and tuffs
	Narrabeen beds		2,000	Shales and tuffs
Permo-Carboniferous	Upper or Newcastle Coal measures		1,600	Shales, sandstones, tuffs, coals, and conglomerates
	Dempsey measures		2,200	Barren shales and some sandstones
	Middle, Tomago, or East Maitland coal measures		1,800	Shales, sandstones, coals, and conglomerates
	Upper Marine series	Crinoidal shales	3,000	Cherts, tuffaceous shales, and clay shales
		Muree rock	400	Sandstone and conglomerate
		Branxton beds	3,000	Mudstones with glacial erratics, and conglomerate or sandstone
	Lower or Greta coal measures		300	Sandstones, shales, conglomerates, and coals
	Lower Marine series	Farley stage	1,000	Chiefly sandstones
		Lochinvar stage	4,800	Mudstones and shales, tuffs, sandstones, lava flows, with tillite at the base
Carboniferous			20,000	Conglomerate, sandstone, quartzite, limestone, shale, and tuff

As in other coal fields, the carbon ratios in Sydney Basin increase somewhat with depth, from upper to lower seams. In certain areas the ratios are too high for the commercial occurrence of oil or gas, while elsewhere the basin is suitable for gas occurrence and possibly for oil occurrence locally.

In some parts of Sydney Basin the coal measures are intruded by dikes, and it is reported that coals have thus been converted locally into natural coke. For this reason Wade believes[1] that if oil be found in New South Wales it will be in the

[1] *Op. cit.*, p. 8.

Upper Marine or Lower Marine series, and he points to the Hunter River area as the most likely locality for suitable structural conditions. The so-called "Lochinvar" dome, which centers 20 miles northwest of Newcastle, is described in classical reports by David,[1] and more recently was reviewed by H. C. Millard for an oil company. The structure, which was visited by the present writer, is apparently a hemidome cut off by a fault on its north side and intruded by the Blair Dugoid igneous mass.

Belford dome is the name given by Millard[2] to a small structure 9 miles northwest of the center of Lochinvar dome. The potentially favorable structural conditions in this part of Sydney Basin were noted long ago by Professor David, and a recent consideration of them is given by Wade.[3] Belford dome surrounds a village of the same name with a complete closure. A boring 1,460 feet deep, sunk in search of coal in the northern part of this dome, reported some "bursts of gas." The carbon ratio of both domes is believed satisfactory for the existence of gas, if not for oil.

Reliable reports exist of oil found in wells near Richmond and Penrith in the eastern part of the basin[4] in a locality which is structurally on the lower part of the Blue Mountain monocline. One of these wells, 4 miles northwest of Penrith and 25 miles northwest of Sydney, is reported 2,700 feet deep, passing through the top of the Narrabeen shales about 1,000 feet from the surface, cutting a 12-foot coal bed at 2,523 feet, and "traces of oil and a large volume of gas are reported to have been met with." A well near Richmond, 15 miles north of Penrith, was 252 feet deep, at which depth the boring rods were "covered with an oily slime"; No. 2 at the same place was drilled 877 feet deep without finding this oil; and No. 3 reported "heavy oil at 200 feet."

In 1917 Mr. J. E. Carne, geologist, and Mr. Mingaye, government analyst, described[5] "marsh gas and an oily scum rising to the surface" of Nepean River (evidently southwest of Penrith) on stirring the mud at the river bottom, and in crevices of a rock ledge. Similar results had been reported by R. Logan Jack and J. Edwards 10 miles farther up the river. All of the gas samples analyzed from the previously-mentioned borings and river sampling were high in nitrogen (30–80 per cent) and low in methane (0–50 per cent). Carne minimized the Penrith oil scums because the site is "situated at a long-used boat landing," and Wade suggests[6] that they may have floated down from the Kerosene Shale-Oil Works of

[1] Sir T. W. Edgeworth David, "The Geology of the Hunter River Coal Measures, N. S. W." *Geol. Survey New South Wales Memoir No. 4*, 1907.

[2] H. C. Millard, "The Lochinvar Dome," *Indus. Austral. and Mining Std.*, Melbourne, July 31, 1924.

[3] *Op. cit.*, pp. 9–10.

[4] Leo J. Jones, "Notes on Petroleum and Natural Gas and the Possibilities of Their Occurrence in New South Wales," *New South Wales Dept. of Mines, Geol. Survey, Min. Res. No. 31* (1921), pp. 25–36.

[5] Leo J. Jones, *op. cit.*, p. 30.

[6] *Op. cit.*, pp. 10–11.

Newnes, on Wolgan River many miles northwest. Observations of the present writer in the locality render him unwilling to accept either explanation without further proof. It may be worthy of note that thin films of oil sometimes cover a large area on the river surface and that similar occurrences are occasionally reported on Mulgan Creek, some hundred yards distant.

Wade is not optimistic regarding the discovery of oil in the Sydney Basin, but believes natural gas may be found commercially, since porous beds and sufficient cover exist and the conditions relative to metamorphism are suitable for gas occurrence. He considers that sufficient geologic work has not yet been done; that Sydney Basin is the most favorable area in New South Wales; that the Upper Marine or Lower Marine series are the most likely strata from which gas may be derived; and that at least one suitable structure exists.

11. EASTERN QUEENSLAND PERMO-MESOZOIC AREAS

In Queensland, east of the Great Artesian Basin, extending from about 150 to about 400 miles north-northwest of Roma, and again through a belt lying 50 to 100 miles further east, are large areas of Permo-Carboniferous and later rocks. They extend, with interruptions, from the New South Wales border north 600 miles to within 120 miles of Townsville. These belts are not personally known to the writer; they may be generally characterized as "coal measures," but contain some mineralized areas. Traces of gas are reported,[1] and sufficiently abnormal structure may exist at places to have accumulated oil locally; but whether or not the necessary fundamental conditions exist has not been proved. The region may deserve some study, being not so easily ruled out of consideration as area 16, described below.

12. WESTERN CAPE YORK PENINSULA, QUEENSLAND

A belt on the eastern shore of the Gulf of Carpentaria is 500 miles long and 50 to 150 miles wide. It consists of Lower Cretaceous to Recent strata that may be continuous with deposits of the Great Artesian Basin, but it is not mapped as an artesian area in any proceedings of the Interstate Artesian Water Conferences. This area of about 40,000 square miles is little known geologically, or otherwise, and nothing can here be said, except that it may deserve geologic investigation.

13. GRAFTON BASIN

In northeastern New South Wales, extending from 20 miles north of the mouth of Clarence River to 40 miles south of it, and having an approximate area of less than 3,000 square miles, is the Grafton Basin of Jurassic and Triassic ages. The strata are mapped as the Clarence series. They are 4,000 feet thick and contain sandstones, shales, and coal beds. The area has been given some attention by Jones.[2] Between 1897 and 1902 a boring for water was sunk to a depth of 3,698 feet

[1] L. C. Ball, "Natural Gas at Cockatoo," *Queensland Government Mining Journal*, Vol. 25 (May, 1924), p. 172.

[2] *Op. cit.*, pp. 33–38.

at Grafton. Natural gas which would burn with a 4-foot flame was tapped at 3,100 feet; coal was found at 3,366 and 3,419 feet, and indications of oil were reported; but the latter could not be verified by Mr. J. E. Carne, the geologist who investigated it, or by Mr. Mingaye, government analyst. The gas contained 62–87 per cent methane, 27–7 per cent nitrogen, and 11–6 per cent oxygen.

At other localities in the Grafton Basin, according to Carne,[1] "a very brief examination was sufficient to dispel any hope" of oil discovery. Jones states:

> Though these Trias-Jura Clarence beds may possess porous strata suitable to act as reservoirs, protected by adequate cover, and suitable geologic structures may be present, still the thick and uniform character of the sediments (most unfavorable for oil accumulation), together with the absence of the necessary organic materials to form large quantities of oil and gas, makes hopeless the prospects of obtaining commercial supplies from such beds.[2]

14. TASMANIAN AREAS

Enthusiastic statements have appeared in the press from time to time with reference to oil occurrence in Tasmania, but the writer can agree with none of these. A sober and helpful review of the oil possibilities of Tasmania has been issued by the government geologist,[3] but no seepages and no true indications are accepted by him as authentic.

Some search for oil has been made in Permo-Carboniferous deposits on Bruny Island, where seepages were reported, but without success. A collection of asphaltum fragments similar to albertite, weighing from an ounce or two up to nearly 100 pounds, can be seen in the Victoria Museum at Launceston, Tasmania, but all are believed to be ocean borne, for they were found between high- and low-tide levels in all cases. The material may emanate from a submarine source or from the Antarctic continent. The prospectus of the Burny Island Petroleum Company, issued in 1915, alleged that liquid petroleum has been known to exude from the ground "in the summer time" at two widely separated places during a period of 50 years, but the validity of these seepages and character of the geology were adversely reported by Wade[4] after careful study. He found that the island consists largely of diabase, with only two small isolated patches of Permo-Carboniferous sandstones having a probable thickness of barely 1,000 feet. The company drilled 430 feet in marine Permo-Carboniferous beds without success.

In other parts of Tasmania, Permo-Carboniferous beds, estimated by the government geologist as being 2,000–3,000 feet thick, have been drilled in search of coal without encountering showings of oil or gas. Although rocks of suitable age exist, they are apparently too greatly broken by intruded igneous masses and are possibly too greatly metamorphosed to hold commercial oil, even though some reports of past seepages may have been authentic.

[1] Leo J. Jones, *op. cit.*, p. 36. [2] *Op. cit.*, p. 38.

[3] W. H. Twelvetrees, "The Search for Petroleum in Tasmania," *Tasmania Mines Dept., Circular No. 2*, 1917. 18 pages.

[4] Arthur Wade, "Petroleum Prospects on Bruny Island," *Parliamentary Paper No. 60*, 1915. 6 pages and 2 maps.

The greater part of Tasmania is formed of diabase, pre-Cambrian, and Cambro-Ordovician rocks. Small separated areas of Trias-Jura beds, totaling 1,200–2,000 feet thick, rest unconformably on the Permo-Carboniferous beds. A few saline lagoons, or "salt pans," overlie Trias-Jura outcrops in "the Midlands," but no oil indications have been reported in association with them. The Launceston Tertiary Basin has an area of only 600 square miles, and other areas of similar rocks are smaller.

The deepest recorded borings in Tasmania are 690 and 894 feet, respectively, Belmont No. 1 and No. 2 "bores" near Langford,[1] and a boring for coal in Tertiary beds near Launceston, which stopped in diabase at 570 feet.[2] Only one seepage of even probable authenticity is reported,[3] issuing from a fault plane in rocks of Permian age in which oil shale and coal are also exposed. In the Mersey district of Tasmania oil shales known as tasmanites exist, from which oil is extracted by distillation, and oil has been distilled from cannel coal or "kerosene shale" at Preolenna.

15. KANGAROO ISLAND AND ADJOINING COASTS

Opposite the mouth of Gulf of St. Vincent in South Australia lies Kangaroo Island, about 85 miles long, on which the occurrence of oil has been rumored and borings have been sunk at Vivonne Bay without success. Reports by Ward and Wade[4] showed the island to be mainly a horst of pre-Cambrian age, and therefore without oil possibilities. Brown,[5] in the only systematic account of the geology of the island, had previously expressed his opinion that the occurrence of asphalt and similar substances on the coast were "purely accidental; that they have been washed up from the sea or deposited by human agency; and that there is not the slightest evidence of their having been derived from local subterranean sources." On the adjoining coast of Eyre's and Yorke peninsulas similar conditions and definite absence of genuine oil prospects were reported.[6] A well 961 feet deep on Kangaroo Island was drilled mainly in quartz-mica schist of pre-Cambrian age. A bibliography of the literature on the geology and oil prospects of Kangaroo Island, Yorke and Eyre's peninsulas, is given by Wade,[7] who states[8] that in his opinion

[1] R. M. Johnston, *The Geology of Tasmania* (1888), pp. 275–76.

[2] W. H. Twelvetrees, *op. cit.*, p. 16.

[3] A. McIntosh Reid, "Natural Oil in the State of Tasmania," *Indus. Aust. and Min. Std.* (September 27, 1923), p. 473.

[4] L. Keith Ward, "The Possibilities of the Discovery of Petroleum on Kangaroo Island and the Western Coast of Eyre's Peninsula," *South Australia Dept. of Mines, Geol. Survey Bull. No. 2*, 1913. 27 plates, 2 maps.

Arthur Wade, "The Supposed Oil Bearing Series of South Australia," *South Australia Dept. of Mines, Geol. Survey Bull. No. 4* (1915), pp. 19–21, 30.

[5] H. Y. L. Brown, *Kangaroo Island*, Report by government geologist, December 13, 1898.

[6] L. Keith Ward, *op. cit.*, pp. 11–13; Arthur Wade, *op. cit.*, pp. 16, 22, 30.

[7] *Op. cit.*, pp. 53–54.

[8] *Jour. Inst. Petrol. Tech.*, Vol. 12, No. 55 (April, 1926), p. 151.

"the whole of the littoral of South Australia is hopeless country in which to seek for commercial supplies of petroleum."

16. BRISBANE COASTAL BELT

The coastal region of Queensland, lying directly east of area 11, is probably not of great importance, although some attention has been given it by geologists.[1] In a belt 450 miles long and 40 to 100 miles wide, bordering the coast from the New South Wales boundary northward, the rocks range in age from Devonian to Recent, interrupted by igneous areas, and no potentially favorable sedimentary area could be over a few miles in extent.

An area to which importance has been attached by some geologists lies near Beaudesert and Boonah, about 30 miles south of Brisbane. The strata appear to consist of 4,000 feet or more of Lower (?) Bundamba sandstones (Triassic) with some thin interbedded shales, 2,000 feet of Upper Walloon (Jurassic) coal measures, in which sandstones predominate, and some shales cut by intrusives and overlain unconformably by about 8,000 feet of basalt and acid volcanic rocks.

The Beaudesert region has in its center the "Overflow" anticline[2] which extends from Mount Jubbera, 7 miles west of Beaudesert, southward 18 miles to Rathdowney, flanked by synclines. The strata near Beaudesert and Boonah are cut by numerous dikes and sills, causing contact metamorphism. Like the anticlines of Desert and Northwest basins, the Overflow anticline lies within a sandstone series in which Morton has shown oil occurrence to be "hopeless." No seepages are known, with the possible exception of "a very thin, pale iridescent film" found in water wells 85 to 375 feet deep in the Baudesert syncline, and percentages of oil found on analysis[3] were as low as .009 to .013 per cent. Only a trace of gas was reported. Wade concludes[4] that the "chances are considerably more than 100 to 1 against finding oil in profitable amounts, even should detailed geological work prove satisfactory closures to the structures that exist."

In the vicinity of Tewantin, near Loguna Beach and Noosa Head, 75 miles north of Brisbane, the strata are of Recent and Mesozoic ages, intruded by andesites and granodiorites. Among six borings, made by two oil companies between 21 and 25 miles north of Tewantin,[5] one was 678 feet deep. Very small "oil showings" were reported in shale and sandstone, but were not evident to the govern-

[1] C. C. Morton, "A Geological Reconnaissance of the Upper Logan and Albert River Watersheds, South Moreton District, with Special Reference to Petroleum Possibilities," *Queensland Mining Journal*, Vol. 24, No. 278 (July 14, 1923), pp. 244–59.

Arthur Wade, *The Possibility of Oil Discovery in Queensland*. Printed for the government of Australia (Melbourne, 1925), pp. 6–9, 1 map.

[2] Wade, *op. cit.*, p. 6.

[3] Lionel C. Ball, "Report on Oil Prospecting at Beaudesert," *Queensland Government Mining Journal*, Vol. 25, No. 293 (October 15, 1924), pp. 263–65.

[4] *Op. cit.*, p. 9.

[5] Lionel C. Ball, "Report on Oil Prospecting near Tewantin," *Queensland Government Mining Journal*, Vol. 25, No. 293 (October 15, 1924), pp. 355–56.

ment analyst. The area is synclinal, and if structures exist they are concealed by surface deposits. Wade did not consider the locality any more favorable than Beaudesert.

A similar verdict awaited a district studied 13 miles south-southwest of Brisbane which was covered in the same report.[1] A boring 866 feet deep, reported[2] as terminating in Triassic beds, had been located by means of a divining rod. Evidences of slight folding are present in Triassic beds and slight evidences of oil were reported, but these may have come from the machinery. Carbon ratios in the neighboring Ipswich coal field were found to average about 70. Borings and shafts sunk in the Triassic rocks in search of coal have revealed no oil evidences.

The literature on oil prospects of Beaudesert and elsewhere is rather extensive;[3] very little of a favorable nature was found in the coastal belt, and, though other areas may be more favorable, nothing is known to indicate this.

17. AREA BETWEEN GREAT ARTESIAN BASIN AND EUCLA BASIN

In central and western South Australia, north of the Trans-Continental Railway, south of Musgrave Ranges, extending west into Western Australia and southeast to Port Augusta, lies a vast area that is neither part of the Great Artesian Basin nor of the Eucla Basin. The area is little known, but the surface rocks seem to be of Pliocene to Recent ages, and contain patches of Upper Cretaceous beds. The area can neither be condemned nor approved at this writing, and may demand exploration.

18. ELCHO ISLAND AND WAGGON LAGOON

Bitumen has been mentioned in the past as occurring on Elcho Island, which is one of the Wessel Islands, only a few score square miles in area, off the north coast of Northern Territory and northwest of Gulf of Carpentaria. Wade states[4] that

[1] Arthur Wade, *op. cit.*, pp. 15–17.

[2] E. C. Saint-Smith, "Boring for Oil at Wolston," *Queensland Government Mining Journal*, Vol. 24, No. 273 (February 13, 1923), pp. 56–60.

[3] Anon, "The Search for Oil: Prospects at Beaudesert," *Queensland Government Mining Journal*, Vol. 23 (October, 1922).

J. H. Reid, "Petroleum Prospects in Beaudesert District: The Overflow and Adjacent Country," *Queensland Government Mining Journal*, Vol. 23 (November, 1922), p. 341.

Anon, "The Search for Oil: Activities at Roma and Beaudesert," *Queensland Government Mining Journal*, Vol. 23 (November, 1922), p. 434.

Anon., "The Search for Oil: The Tewantin Concessions, Etc.," *Queensland Government Mining Journal*, Vol. 24 (June, 1923), p. 200.

C. C. Morton, "A Supposed Oil Seepage, Bulimba," *Queensland Government Mining Journal* Vol. 25 (January, 1924), p. 12.

Anon, "The Search for Oil: Good Showing of Gas at Beaudesert," *Queensland Government Mining Journal*, Vol. 25 (September, 1924), p. 319.

L. C. Ball, "Oil Prospecting near Beaudesert," *Queensland Government Mining Journal*, Vol. 25 (1924), pp. 362–64.

L. C. Ball, "Oil Prospecting near Tewantin," *Queensland Government Mining Journal*, Vol. 25 (October, 1924), pp. 354, 361.

[4] *Jour. Inst. Petrol. Tech.*, Vol. 12, No. 55 (1926), p. 156.

the country rocks are "indurated pre-Cambrian flags, shales, and quartzites," almost horizontal or dipping at low angles. "In the shaly layers between quartzitic bands are found isolated flat cakes of very hard bitumen about 1 inch in thickness, and sometimes about 1 foot in diameter. They are distributed almost in the same manner as are concretionary nodules in shale-beds." Wade regards these deposits as "the final remnant of what must have been a more important accumulation of bitumen, and we may have here the last stages of an even older accumulation of oil than that which may have existed in the Ord River Basin." A similar deposit is mentioned by the same writer near Roper River at Waggon Lagoon, 300 or 400 miles inland from Port Darwin. He found bitumen impregnating vesicular basalt at its contact with quartzites, shales, and flags like those of Elcho Island. Specimens of "rich oil shale" are reported from Elcho Island, but are probably "waifs of the sea."[1] Area 18 is described more fully by Wade, but nothing favorable is known with regard to it.

RANDOM DRILLING IN OTHER AREAS

Desultory drilling has been done near Albany on the Antarctic Ocean 240 miles southeast of Perth in Western Australia, but the hole stopped on granite at 237 feet, and it is reported not to have penetrated stratified rocks aside from 135 feet of clay carrying petrified wood and pyrites. The locality is granitic with merely a fringe of eolian and other Recent deposits and has been unfavorably reported by the government geologist.[2] Wade described[3] the coast between Eucla Basin and Coastal Plain Basin—a distance of about 600 miles—as "a most interesting series of metamorphic rocks," evidently of Archean age, with only local thin coverings of Tertiary and Recent date. In these later rocks he "could see no signs whatever of favorable structural conditions," and stated that "it is useless to bore for oil" in that region.

In addition to the wells previously mentioned, other borings may have been sunk for oil in similarly unfavorable areas, but researches of the writer have been too short to itemize them.

FALSE OIL INDICATIONS OF THE ANTARCTIC COAST

About 1902 sensational reports appeared in the press and in pamphlets circulated by promoters and by self-styled "oil experts" calling attention to bituminous deposits found on the coast of the Great Australian Bight, west as far as Indian Ocean and east to the Pacific. Traces of oil were reported "in the sand dunes," and other traces were said to float on the sea. Similar rumors of oil occurrence have come every year from isolated coastal points throughout a distance of nearly

[1] *Petroleum Prospects: Kimberley District of Western Australia and Northern Territory.* Printed by order of the Senate (October 8, 1924), pp. 36–37.

[2] A. Gibb Maitland, "The Geology of Princess Royal Harbour, with Reference to the Occurrence of Oil," *Western Australia Geol. Survey Bull. 26* (1907), pp. 27–33 and geol. map.

[3] "Report on Petroleum Prospects in Parts of Western Victoria, South Australia, and Western Australia," *Australian Government Parliamentary Paper* (1926), pp. 2–3.

3,000 miles. The deposits are in part asphaltum washed up by the waves, sometimes in large masses and at widely separated points, but the material has never been found inland or away from localities accessible to wave action.

These false oil "indications" were carefully studied by Ward[1] from Hog Bay (or Wilson) River on the south coast of Kangaroo Island, and from several beaches in Victoria, South Australia, and Western Australia. One lump was reported by Gibb Maitland from Indian Ocean as far north as Mandurah, near Perth. The writer, in visits to Melbourne and Adelaide, was besieged by persons who could show samples which they believed to be derived from oil seepages; but on a study of the locality the geology was always found to be unfavorable. Even where the material was reported "oozing out of the rock" the statement was found to be a mistake, for the coast of Eyre's Peninsula, on which these deposits are most often reported, consists mainly of pre-Cambrian pegmatites, granites, gneisses, and metamorphic schists.

As on the south side of the mainland of Australia, as also on the Tasmanian coast, stray lumps of bitumen have appeared from time to time, and many attempts have been made to locate their source. They were found on Prime Seal Island (Hummock Island) in the Straits by Charles Gould, government geologist, as long ago as 1871; on the west coast of Tasmania, both north and south of Sandy Cape, by T. B. Moore in 1876; later by the same investigator in Macquarie Harbor (near Farm Cove) and near Point Hibbs[2] and at the mouth of Mainwaring River. The known discoveries of such material have been enumerated by Twelvetrees.[3] Water-worn resins have also been collected on the same coast, and one reported occurrence of ozokerite was tested by a government analyst and found to be beeswax.[4]

In 1914 efforts were made to drill for this substance, then believed indigenous to the localities where found, on the South Coast at New River, Rocky Boat Harbor, and other places, and a geological examination was made, but the fragments were found to be washed up by the sea. Similar unsuccessful drilling attempts were made at Port Davey Harbor, Tasmania, where pre-Cambrian schists are dominant. The literature on these occurrences is voluminous, and the falsity of the alleged Australian derivation of the material has been proved by various geologists. According to Woodward, the south-southwesterly gales, striking obliquely on the Antarctic current coming from the southeast, have deposited the material on the Australian coast.[5]

In South Australia appreciable quantities of a brown, leathery, or rubber-like material, gathered in small flakes from the shore, have been given the name of

[1] L. Keith Ward, *South Australia Dept. of Mines, Geol. Survey Bull. No. 2* (1913), pp. 13–20.

[2] Loftus Hills, *Tasmania Geol. Survey Bull. 18.*

[3] W. H. Twelvetrees, *Tasmania Geol. Survey Bull. 24.*

[4] L. Keith Ward, *op. cit.*, p. 22.

[5] H. P. Woodward, *West Australia Geol. Survey Bull. 65* (1915), p. 24.

"coorongite[1] (often referred to as "solidified oil-cake"). It is generally mixed with dry grasses, and analysis has shown it to be a product of diatomaceous growth on lagoons of brackish water. From it a dark brown liquid can be obtained which resembles crude oil.

Investigation of the origin of coorongite has been intensive, beginning with tests made by Jackson in 1872[2] and continuing through the analyses of W. A. Hargreaves[3] in 1903, Cumming[4] in 1902, and the studies of Ward and Wade.[5] Numerous other writings on the subject have appeared,[6] and the controversy relative to its origin has been heated. A partial bibliography of the subject is given by Ward,[7] and by Wade, who agrees with the opinions of Ward and Woodward and gives a three-page bibliography of works on oil prospects of South Australia.

OIL SHALES OF AUSTRALIA

According to E. F. Pittman, former government geologist of New South Wales, the term "kerosene shale"[8] is applied in that state to "a variety of torbanite, cannel coal, or boghead mineral" which occurs at several localities and in at least three horizons of Permo-Carboniferous age.

The name kerosene shale is an unsatisfactory one, because the mineral has little or none of the characters of shale, in that it does not, at any rate in hand specimens, cleave or split readily parallel to the laminae, which latter, as a rule, are only visible in weathered specimens. It is a dense brownish-black substance, devoid of lustre, and has a most characteristic conchoidal fracture. Its streak is buff colored; when of good quality it ignites readily with a match, and continues to burn with a luminous smoky flame after the match has been withdrawn. It can be readily cut with a knife or turned in a lathe, and is tough and elastic; the latter characteristic has frequently been the cause of accidents, as the shale has a tendency, when being wrought in mines, to fly out in large pieces, which are liable to cut or otherwise injure the miners. The weathered surfaces of the mineral are usually of a light-gray color, and there is frequently a thin film of whitish clay in the joints.

Rich deposits of "kerosene shales" in Wolgan and Capertee valleys, about 100 miles west of Sydney, have been described by Carne[9] in an excellent monograph.

[1] From the Coorong, a narrow coastal lake extending southeast about 90 miles from the mouth of Murray River.

[2] J. R. Jackson, *Pharmaceutical Journal* (1872), pp. 763, 785.

[3] L. Keith Ward, *op. cit.*, pp. 16–17.

[4] Alex C. Cumming, "Coorongite, a South Australian Elaterite," *Proc. Roy. Soc. of Victoria*, Vol. 15, N. S., Par 2 (1902), pp. 134–40.

[5] Arthur Wade, "The Supposed Oil-Bearing Areas of South Australia," *Geol. Survey South Australia, Bull No. 4* (1915), pp. 36–37.

[6] W. T. T. Dyer, "On a Substance Known as Australian Caoutchouc," *Journal of Botany* (1872), pp. 103–4.

E. O'Meara, "The Diatoms in the Australian Caoutchouc," *Quarterly Journal of Microscopical Science*, Vol. 13, N. S., p. 211.

[7] L. Keith Ward, *op. cit.*, p. 19.

[8] John Plummer, "The Australian Shale Industry," *Mining World* (December 12, 1908).

[9] J. E. Carne, *New South Wales Geol. Survey, Memoir Geol. No. 3*, 1903. 333 pages.

Gambage[1] has estimated "the probable kerosene shale reserves in the Carpertee-Wolgan–Glen Alice area" at approximately 20,000,000 tons, and the average content of crude oil per ton of shale as 100 gallons. He gives 50,000,000 barrels of shale oil as available in this area, and estimates the shale-oil capacity of the state at some 85,000,000 barrels. Although this estimate is important and cannot be overlooked, nevertheless actual investments by Commonwealth Oil Corporation in this venture resulted in dismal failure. The company which worked the deposits expended large sums unprofitably, and the mines and works are falling to decay, owing to increasing cost of labor, errors in development, remoteness from satisfactory transportation, and the fact that the seams are too thin to compete with petroleum at present prices. As a matter of fact, the thickness of the "kerosene shale" beds ranges from 1 foot, 2 inches, to 4 feet, 2 inches. According to Gambage the products derived from this oil are as follows:

PRODUCTS DERIVED FROM OIL FROM "KEROSENE SHALES"

Product	Percentage
Gasolene (or benzine)	5
Kerosene	20
Gas oil	25
Fuel oil	20
Paraffin wax	5
Loss in treatment	25
Total	100

"Rich oil shales" also exist in Tasmania, where they are worked at Latrobe by the Australian Shale Oil Corporation. In 1925 the reserves were estimated[2] as 7,750,000 tons, some shales showing an oil content of 40 gallons per ton. Deposits in Mersey Valley[3] are controlled largely by the Railton Latrobe Oil Company,[4] which estimates its prospective yield as 55 gallons of oil per ton, but the output to date is small. Another "rich cannel or torbanite" exists at Preolenna, but the beds are thin. Tasmanian shales were reported capable of yielding 13,000,000 barrels of oil.

In Queensland some Tertiary oil shales exist in the Port Curtis district and near Ipswich and Toowoomba.[5] In Western Australia an oil shale of limited extent at Coolgardie is reported to yield 30 gallons of oil per ton.[6]

[1] R. H. Gambage, "Presidential Address," *Roy. Soc. New South Wales* (May 7, 1924), p. 45.

[2] Press notice.

[3] W. H. Twelvetrees, "The Tasmanite Shale Fields of the Mersey District," *Tasmania Dept. of Mines, Geol. Survey, Bull. 11*, 1921. 123 pages, 1 map.

[4] Arthur Wade, "Report on the Financial Position, Requirements, and Prospects of the Railton-Latrobe Shale Oil Company," *Tasmanian Government Paliamentary Paper* (Hobart, 1916).

[5] L. C. Ball, "Oil Shale of the Port Curtis District," *Queensland Geol. Survey, Publication 249*, 1915. 35 pages and 2 figs.

[6] *Report, Mines Dept. of Western Australia*, 1904.

The oil-shale situation of Australia has been summarized by Thwaites,[1] who finds that the New South Wales kerosene shales are lentils rarely more than a mile in length; that the total amount of shale mined in the past 70 years was 1,900,000 tons; that 1,000,000 tons per year must be mined in order to meet Australian requirements; and that "there does not appear to be any prospect of meeting more than a fraction of the country's oil needs from this quarter." He concludes that the oil shale deposits of Australia "might possibly supply Australian needs for 30 years at the present rate of consumption," but that, "on a long view the resource appears inadequate." He analyzes the coal situation of Australia and finds that, if coal be treated instead of shale, the supplies would be "sufficient to meet all possible demands for many hundreds of years." He emphasizes the need for a Commonwealth fuel-research institute.

ATTITUDE OF THE GOVERNMENT

In the past the Commonwealth government and some of the state governments have encouraged the search for oil by offering bounties for its discovery. The Commonwealth bounty offer of $250,000 was withdrawn in 1925 on advice of Dr. Arthur Wade, government geologist, and the state geologists, who considered that the money could better be put into geological work and into subsidizing companies to drill in promising localities. In accordance with that advice, the government decided to utilize the sum in the form of subsidies in the Hunter River district of New South Wales, at Price's Creek, Western Australia, and on geological work at Longreach, Blackall, and Ruthven, Queensland.

CONCLUSION

In the introductory part of this paper it has been shown that a difference of opinion exists in Australia as to whether the continent has any chance of proving oil-bearing. Most of the unfavorable comprehensive views expressed to date have been on the basis of broad generalizations. In some parts of the country, however, as throughout Western Australia and Tasmania, the greater part of Northern Territory, and most of Victoria, Wade, Ward, the writer, and others have been able safely to eliminate vast areas as probably unfavorable on the basis of fundamental conditions. The writer has not gone on record as opposed to the probability of oil in Australia. On the contrary, he is of the opinion that somewhere in the eastern part of the continent a few commercial oil pools may exist. Only the most favorable areas geologically are worth testing, and these should not be drilled until detailed studies have been made of them. So far as the writer is aware, no "detailing" of structures has ever been done in Australia to the refinement with which it is practiced by American geologists in New Zealand and other potentially favorable countries.

[1] R. E. Thwaites, "The Production of Liquid Fuels from Oil Shale and Coal in Australia," *Inst. of Science and Industry*, Melbourne, 1923, 62 pages and map.

GEOLOGICAL NOTES

OCCURRENCE OF OIL IN BASALT IN SOUTHWESTERN WASHINGTON

Oil has been found in igneous rocks at so many localities throughout the world that it may not seem worth while to call especial attention to another such locality which has not yet been noted in the geologic literature. The existence of small amounts of a semi-solid oil in veins which cut Eocene basalts in Pacific County, Washington, does, however, appear to be worthy of note, inasmuch as the mode of occurrence of the oil is somewhat different from any heretofore described and, furthermore, because the evidence permits rather positive conclusions as to the derivation of the hydrocarbons.

The best opportunity for the study of this phenomenon was afforded by a quarry in Eocene volcanic rocks, in NE. ¼ of Sec. 32, T. 10 N., R. 11 W., 1 mile west of Ilwaco, Pacific County, Washington. The rock exposed immediately northwest of the quarry is a very fine-grained basalt, undoubtedly representing a lava flow. Along the beach south of the quarry the igneous rock is vesicular and in part agglomeratic, indicating that it also is flow material. The rock of the quarry is a decomposed, fine-grained, gray, basic igneous rock, which shows no definite evidence of having consolidated from a lava flow. At the west end of the quarry a mass of shale and sandstone, lithologically similar to rocks of the Oligocene-Miocene series of this region (Astoria shales), is included in the igneous rock in the form of a very thin synclinal wedge, striking N. 70° W. At one locality the shale has been converted to a substance resembling jasper, and at other places both sandstone and shale are impregnated with ferruginous opal. The igneous rock near the contacts with the sedimentary mass is of somewhat finer grain than elsewhere.

While there is abundant evidence proving that the igneous rock is in "intrusive contact" with the sedimentary mass, yet from the general field relationships and from the failure of the writer to find any dividing plane between the rock exposed in the quarry and the rocks to the south, which are certainly not of intrusive nature, it is concluded that the rock in contact with the sediments is a part of the volcanic series of this region. It is believed that the fragment of sedimentary rock represents a mass of shale and sandstone which, having been formed in the ocean during a cessation of volcanic activity, was plucked from its original position by an advancing lava flow, carried forward by the molten rock, and remained as a foreign body in the lava at the time of its consolidation.

Veins of calcite and zeolites cut the igneous rock in the vicinity of the mass of sediments. The minerals of these veins are frequently stained to a honey-yellow color by a substance which yields a brown solution with ether, and drusy cavities in the veins are partially filled with a brown, semi-solid grease having the general appearance of vaseline.

At Dead Man's Hollow, 1½ miles southwest of the Ilwaco Quarry, Oligocene marine shales rest conformably upon amygdaloidal basalt of presumed Eocene age. The basal sandstone of the Oligocene series which occurs elsewhere in this region is absent at this particular locality. The contact between the volcanic and sedimentary rocks is gradational, several thin layers of marine shale being intercalated with basalt layers below the

base of the main body of shale. This relationship indicates that the Eocene basalts of this region, in part at least, consolidated below the surface of the sea, the intercalated shales having been deposited during periods of cessation of volcanic activity. The upper portion of each of these shale beds is hardened, presumably by the heating action of the overlying lava flow, while the lower portion of each layer is entirely unaffected by such action. The uppermost portion of one shale layer has been altered to a dense, gray material resembling jasper, and veins of gray jasper and of calcite cut the basalt at numerous localities. Some of the calcite of the veins is stained yellow by a substance, presumably a hydrocarbon, soluble in ether.

It is believed that the calcite, jasper, and the supposed hydrocarbon substance were derived from the shales and distributed to form the veins by heated circulating waters.

Volcanic agglomerate of Eocene age exposed on the north side of the railway, in NW. ¼ of Sec. 21, some 300 yards northwest of the west portal of Fort Columbia tunnel, is cut by a 3-inch vein of banded gray jasper which contains drusy cavities filled with brown grease. This hydrocarbon is thought to have been derived from shales which underlie the volcanic rock.

A somewhat similar occurrence of heavy oil, in the amygdules and crevices of a vesicular volcanic sill or dike exposed on the Johnson ranch, 6 miles from Florence, Lane County, Oregon, on the east side of North Fork of Suislaw River, has been described by Harrison and Eaton.[1] They state that the volcanic rock has been intruded so as to lie immediately above a dark bed of shale about 4 feet in thickness.

Although some members of the Astoria series have characteristics similar to typical oil shales, no oil has yet been found in Pacific County save in veins cutting basalt. It is concluded, therefore, that the heat of the molten lava was necessary to produce hydrocarbon substances from oil-forming materials present in the shale, and that these hydrocarbons were circulated through the fissures of the igneous rock, after its consolidation, by the same solutions which deposited the calcite and zeolites.

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Los Angeles, California

SCHIST EAST OF SANTA ROSA, NEW MEXICO

The test of the Peerless Oil Company in Sec. 5, T. 8 N., R. 23 E., Guadalupe County, New Mexico, was abandoned in schist at a depth of 1,771 feet during May, 1926.

This test was drilled on the Juan de Dios Creek, south of the O. T. Highway, 9 miles east of Santa Rosa, New Mexico. It starts in the Triassic, 200 feet above the Santa Rosa Sandstone. The San Andres lime was found from 1,105 to 1,175 feet. The schistose material was encountered at 1,585 feet. Between 1,175 and 1,585 feet the log reports sands with some red beds.

F. S. Prout

AGE OF THE OIL IN THE MIOCENE SHALES OF THE VENTURA DISTRICT, CALIFORNIA

The occurrence of pebbles of burnt shale in beds of the Fernando group (Pliocene) of the Ventura quadrangle, California, suggests that petroleum had been formed in the Miocene shales before the deposition of the Fernando.

[1] *Min. Res. Oregon*, Vol. 3 (1920), No. 1, p. 26.

Geologists who have worked in the southern coast ranges, in Santa Barbara and Ventura counties, especially, are familiar with the phenomenon of burnt shale outcrops in the light organic shales of the Miocene series, variously designated as the Monterey, Salinas, Modelo, or Puente formation. Such outcrops are not uncommon in the Ventura and Santa Paula quadrangles just east of Santa Barbara and north of Los Angeles. In a recent report on an area to the east, Kew[1] mentions outcropping burnt shale as a surface indication of the presence of petroleum. Arnold and Anderson[2] discuss the occurrence of outcrops of burnt shale in eight or ten separate localities of the Santa Maria oil district, Santa Barbara County, the largest outcrop extending over an area of one-half square mile. The writer has recently examined ten such outcrops, none more than 50 feet across, within a distance of 18 miles in the Ventura and Santa Paula quadrangles.

The unaltered shale is white, buff, or brown; thin-bedded and brittle; opaline in some beds and very calcareous in others. It is sometimes petroliferous, and is occasionally interbedded with soft, brown sandstone, also petroliferous. At many places in these quadrangles, notably along the south side of Sulphur Mountain and at the mouth of Carpinteria Creek, a viscous, black oil having a distinct odor of sulphur is seeping out of fractures in the rock. A dry, asphaltic residue marks many seepages no longer active.

The burnt shale generally occurs in the vicinity of these seepages. It exhibits all degrees of alteration, from a slight discoloration of the rock to extreme hardening and partial fusion. The slightly changed shale assumes a light pink color, probably due to oxidation and dehydration of iron compounds, without change of texture. As alteration progresses, the shale becomes very hard and brick-red in color, resembling well-baked tile. In the ultimate stage of metamorphism observed, the rock is deep red to black, scoriaceous, and resembles vesicular lava. Under the miscoscope this scoriaceous rock is seen to consist of a red- and black-flecked glassy groundmass, with a few angular, detrital grains of quartz, feldspar, and chalcedony scattered through it. The groundmass is isotropic and has an index of refraction higher than balsam.

Arnold and Anderson[3] ascribe the metamorphism of the shale to combustion of the hydrocarbons in it. They cite instances where the oil in the shale has been seen to burn, with the emission of flame, smoke, and sulphurous fumes. They believe that the causes of ignition may be kindled fires, brush fires, lightning, or spontaneous combustion of the hydrocarbons. This explanation seems acceptable, especially since there are no phenomena of igneous intrusions in the vicinities of these outcrops, and no coal seams.

The pebbles found in the Fernando group (Pliocene) and identified as burnt shale were six in number. Five of these were found in a conglomerate bed exposed in the hills 3½ miles north and east of the town of Ventura, between the headquarters of Manuel Canyon and Hall Canyon. Stratigraphically, the bed occurs at least 7,000 feet above the base of the Fernando. One pebble was found in a conglomerate bed cropping out near the mouth of Los Sauces Creek, 8 miles northwest of Ventura. Due to faulting, this bed cannot be located stratigraphically. The pebbles in each instance were of the brick-red variety, faded on the exterior and softened by weathering. The conglomerate beds in which

[1] W. S. W. Kew, "Geology and Oil Resources of a Part of Los Angeles and Ventura Counties, California," *U.S. Geol. Survey Bulletin 753* (1924), p. 115.

[2] Ralph Arnold and Robert Anderson, "Metamorphism by Combustion of the Hydrocarbons in the Oil-Bearing Shale of California," *Jour. Geol.*, Vol. 15 (1907), pp. 750–58.

[3] *Op. cit.*, p. 757.

they were found contained a large number of Miocene shale fragments, some of which were thoroughly impregnated with limonitic stain. Some of the stained ones may represent burnt shale in which the ferric oxide has been hydrated by weathering processes.

If one accepts the explanation that the metamorphism is due to the burning of accumulated oil at, or close to, the surface, analogous to the local metamorphism of sedimentary beds by burning coal seams, the occurrence of fragments of burnt shale in the younger formation as described is evidence that *oil was in the older shales before the conglomerate beds were laid down; in other words, before or during the Pliocene epoch.* The contact relationships between the Miocene and Fernando beds indicate that the Miocene was only slightly, if at all, deformed in this vicinity before the deposition of the Fernando. Hence, it would appear that *the forming of petroleum in the Miocene beds was not an accompaniment, necessarily, of the diastrophism recorded in their complex structures.*

LON D. CARTWRIGHT, JR.

STANFORD UNIVERSITY, CALIFORNIA
November 17, 1926

OKLAHOMA GEOLOGICAL SURVEY

EIGHTH FIELD CONFERENCE, NOVEMBER 9-17, 1926

The Eighth Field Conference under the auspices of the Oklahoma Geological Survey was in many ways the most successful that has yet been conducted. Thirty-six men participated in the conference. The total distance traveled was approximately 1,500 miles, including parts of Oklahoma, Texas, and New Mexico. The general itinerary was as follows:

November 9.—The party left Oklahoma City, driving west through El Reno, Geary, Bridgeport, Weatherford, Elk City, and Sayre, studying on the way the outcrops of the Permian formations, including the Duncan, Blaine, Dog Creek, Whitehorse, Day Creek, and Quartermaster. Drove through the Sayre oil field, and to Shamrock, Texas, for the night.

November 10.—Leaving Shamrock, the party drove southwest to Memphis, studying the Whitehorse formation and the Channel sandstone which caps a number of buttes in that region. Then to Clarendon and Claude, where a detour was made to Palo Duro Canyon, where examination was made of the Tertiary, Triassic, and Permian beds there; thence to Amarillo for the night.

November 11.—Visited the Amarillo oil fields at Borger, Hutchinson County, making studies of the Day Creek (Alibates) dolomite and certain structural problems.

November 12.—Drove north from Amarillo, crossing Canadian River, studying the Day Creek (Alibates) dolomite on the John Ray dome, on which was located the first gas well in the Panhandle. Thence west past Channing, Texas, to Nara Visa and Logan, New Mexico. Studied the Santa Rosa (basal Triassic) sandstone. To Tucumcari for the night.

November 13.—Drove from Tucumcari west past Montoya and Cuervo to Santa Rosa. Thence down the Pecos River to study the Permian outcrops near Puerta de Luna. The concensus of opinion was that this Permian represents the Cloud Chief and Quartermaster formations of Oklahoma. After lunch at Santa Rosa the party drove west to Pintada Canyon, where studies were made of the upper Permian, including the San Andres and superjacent formations (Cloud Chief and Quartermaster). Thence north to the Esteritas

dome, and back to Santa Rosa for the night, where the chamber of commerce tendered the visiting geologists a chicken dinner.

November 14.—Drove from Santa Rosa to Vaughn; thence to Duran, climbing the Duran Mesa, where there are exposed in ascending order the Yeso, Glorieta, and the San Andres formations of the Permian. Lunched at Encino, and then drove to the Pedernal Mountains, north of that place. These mountains consist of quartzite monadnocks which were probably buried during Permian times, and are now being uncovered by erosion, very much like the Wichita Mountains of Oklahoma. Drove north across Triassic and Permian beds to Lamy, and to Santa Fe for the night.

November 15.—From Santa Fe, drove southwest, passing over the igneous rocks which represent the southeast section of Sangre de Cristo range to Glorieta; thence southeast for 50 miles along the western flank of the Glorieta Mesa. The rocks exposed are, in ascending order: Magdalena limestone (Pennsylvanian), and the Abo, Yeso, and Glorieta formations of the Permian. To Las Vegas for lunch; thence southeast to Santa Rosa, the road leading down a valley between hogbacks formed by Santa Rosa and Glorieta to the west and the high Mesa of upper Wingate (Jurassic) and Dakota to the east. Past Anton Chico (Esterita) dome, through Santa Rosa, and to Tucumcari for the night.

November 16.—At Tucumcari the party divided, part going northeast to Texas and Beaver counties, Oklahoma, and others through Amarillo, Clarendon, Memphis, and Childress for the night.

November 17.—From Childress, drove across southwestern Oklahoma to Norma, studying the outcrops of the Blaine, Dog Creek, and higher Permian formations.

A summary of the tentative conclusions arrived at on this conference follows:

The San Andres of New Mexico is the approximate equivalent of the Blaine of Kansas, Oklahoma, and northern Texas.

The Glorieta sandstone of New Mexico is the approximate equivalent of the Duncan-San Angelo.

The Yeso of New Mexico is the approximate equivalent of the Hennessey and Garber formations of Kansas and Oklahoma, and of the Clear Fork of Texas.

The Abo of New Mexico is the approximate equivalent of the Flint Hills section, including Council Grove, Chase, and Marion groups of Kansas, the Stillwater of Oklahoma, and the Wichita-Albany of Texas. The Abo is also believed to be the equivalent of the Hueco of the trans-Pecos region of Texas.

The correlation of the post-Blaine equivalents along the Pecos River are not thoroughly understood, but it is strongly suspected that the Rustler dolomite is the approximate equivalent of the Day Creek (Alibates).

Charles N. Gould, *Director*

LIST OF MEN IN ATTENDANCE ON THE EIGHTH FIELD CONFERENCE, NOVEMBER 9-17, 1926

E. H. Sellards, Bureau of Economic Geology and Technology, Austin, Tex.
John L. Rich, consulting geologist, Ottawa, Kan.
V. E. Monnett, University of Oklahoma, Norman
H. C. George, University of Oklahoma, Norman
C. E. Decker, University of Oklahoma, Norman
John R. Bunn, consulting geologist, Ardmore

J. V. Howell, Marland Oil Company, Amarillo
Robin Willis, Marland Oil Company, San Angelo
R. L. Heaton, Marland Oil Company, Denver
J. J. Maucini, Marland Oil Company, Amarillo
V. W. Watson, Marland Oil Company, Amarillo
F. S. Prout, Empire Oil Company, Roswell
C. M. Boos, Empire Oil Company, Amarillo
C. Max Bauer, Mid-West Oil Company, Amarillo
R. K. DeFord, Mid-West Oil Company, Amarillo
Joe Patterson, Pure Oil Company, Amarillo
David Hedley, Pure Oil Company, Amarillo
M. E. Roberts, Pure Oil Company, Amarillo
W. B. Hoover, Humble Oil & Refining Company, Amarillo
Morgan J. Davis, Humble Oil & Refining Company, Roswell
F. B. Smith, Humble Oil & Refining Company, Roswell
F. W. Bartlett, Roxana Petroleum Company, Amarillo
C. W. Sanders, Roxana Petroleum Company, Tucumcari
H. J. Temler, Roxana Petroleum Company, Amarillo
N. P. Isenberger, Amarada Oil Company, Amarillo
F. O. Reynolds, I.T.I. Oil Company, Roswell
E. A. Keeler, Sinclair Oil Company, Amarillo
L. C. Roberts, Jr., S. Crude Oil Purchasing Company, Amarillo
H. A. Stewart, Texas Company, Denver
Hal. S. Vaughn, Shamrock Oil Company, Tex.
Jack Brandenburg, University of Oklahoma, Norman
James Manatt, Amarillo
James Nolan, Amarillo
C. L. Cooper, Oklahoma Geological Survey, Norman
Chas. N. Gould, Oklahoma Geological Survey, Norman

REVIEWS AND NEW PUBLICATIONS

Logarithmic Stadia Rod for Topographic Work and Area Measurements. By John R. Jahn. *Engineering News-Record* (July 8, 1926), p. 71.

The stadia rod (illustrated) gives rod readings which are the logarithms of the number of feet intercepted on the rod by the stadia wires of the transit. The chief advantage of the scale lies in the improved visibility of the divisions on the rod's scale at the transit.

The rod has a target, on which the lower stadia wire is to be set, and the divisions increase in width proportionately with increasing distance from the target. As the stadia rod moves away from the transit the upper stadia wire of the transit registers farther along the rod, cutting larger divisions. This reduces the strain in taking distant shots and makes rapid readings at all reasonable distances possible, because the observer's eye becomes accustomed to the constant width of intervals.

In reading cross-vertical angles, both rod intercepts and vertical angles may be read at once. Reduction of notes to give elevations above any given datum is simplified. The logarithmic horizontal distances are plotted, using logarithmic scales similar to the field rod and of the required reduced size to give maps of the desired scale.

The logarithmic feature is very useful in estimating acreage in reasonably flat country. The transit is set up in the middle of the field and a rodman walks around the boundary, giving rod readings at all angle points. Two adjacent rod readings designate a triangular section of the field. Their sum, plus the sine of the included angle, plus a constant (9.060) is the logarithm of the area of the section in acres.

The reviewer suggests that everyone interested should read the entire article and should make a practical investigation system.

Arthur Knapp

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The Executive Committee has approved for publication the names of the following applicants for membership in the Association. This does not constitute an election, but places the names before the membership at large. In case any member has information bearing on the qualifications of these applicants, please send it promptly to J. P. D. Hull, Business Manager, Box 1852, Tulsa, Oklahoma. (Names of Sponsors are placed beneath the name of each applicant.)

FOR FULL MEMBERSHIP

Charles R. Hoffmann, Pechelbronn, France
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Eugene Jablonski, Boryslaw, Poland
Winthrop P. Haynes, Ray P. Walters, A. E. Fath
Emil Kluth, Los Angeles, Calif.
Sidney Powers, Luther H. White, Edward Bloesch
Garfield C. Siverson, Tulsa, Okla.
A. A. Langworthy, A. I. Levorsen, L. L. Foley
Stuart Weller, Chicago, Ill.
F. B. Plummer, Raymond C. Moore, Charles E. Decker
Robin Willis, Stanford University, Calif.
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Eustace John Coel, El Limon, Mexico
Charles L. Baker, W. M. Small, William A. Baker, Jr.
Leo Sanor Fox, Los Angeles, Calif.
C. M. Wagner, A. S. Hayes, Wilson C. Giffin
Harold Warren Haight, Golden, Colo.
F. M. Van Tuyl, Charles M. Rath, Max W. Ball
Bruce H. Harlton, Tulsa, Okla.
Dollie Radler, A. F. Truex, L. B. Snider
Gladys Willetta Hawley, Tulsa, Okla.
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Andrew McDonald Hazzard, Oil Field, Fresno County, Calif.
E. F. Davis, Roy R. Morse, Guy E. Miller
Albert Lee Jones, San Antonio, Tex.
Charles H. Row, Frederic H. Lahee, R. E. Rettger

Floyd William Ohliger, Pittsburgh, Pa.
K. C. Heald, R. E. Somers, R. S. Knappen
Thomas Hartman Olds, Denver, Colo.
Thomas S. Harrison, E. Russell Loyd, C. A. Fisher
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K. C. Heald, L. G. Huntley, Shirley L. Mason
Warren Osborne Thompson, Boulder, Colo.
John G. Bartram, Charles M. Rath, Max W. Ball

FOR TRANSFER TO FULL MEMBERSHIP

Roland Leroy Clifton, Enid, Okla.
Charles N. Gould, C. W. Tomlinson, Glenn C. Clark
John Human Wilson, Tampico, Tamps., Mexico
Charles M. Rath, Ellis A. Hall, Carroll H. Wegemann

TWELFTH ANNUAL MEETING TO BE IN TULSA

The twelfth annual meeting of the American Association of Petroleum Geologists will be held in Tulsa, Oklahoma, March 24–26, inclusive, 1927. The Mayo Hotel will be Association headquarters.

The personnel of the committee on arrangements for this meeting is as follows: chairman, M. M. Valerius; finance, J. H. Gardner; program, Sidney Powers; publicity, Luther H. White; reception, L. G. Welsh; registration, Frank A. Herald; exhibits, Frank C. Greene; entertainment, Harry H. Nowlan; ladies' entertainment, T. E. Weirich; golf tournament, A. L. Beekly; hotels, G. C. Potter; transportation, A .W. Duston; banquet, Richard Hughes; decoration, V. H. Hughes.

The program is being arranged as follows: (1) papers dealing with new fields in active development (Thursday forenoon), (2) general papers, and (3) symposium on the relation of structure to petroleum accumulation as revealed by our knowledge of the oil fields of the United States. Papers are being prepared on individual fields or groups of fields giving particular attention to structure contour maps. It is hoped that these papers can be reprinted in a separate volume which will form a book on structural geology of oil fields, with critical reviews of structural problems by well-known geologists. Presentation of the papers is to be by lantern slides of structure contour maps, and nothing but structure and the relationship of oil and gas in different horizons is to be discussed. Other papers for which lantern slides are not available are to be read by title, and, together with the maps, will be exhibited in a room for that purpose. Most of the papers which are being solicited for this symposium cannot be presented orally because of the limited amount of time available.

The Executive Committee has authorized the Program Committee to select papers for oral presentation in order that ample time may be available for complete presentation and discussion of the papers which are considered to be of interest to the majority of the membership.

A special session for the Paleontological Section will be held Friday morning.

A special session for geophysical and technological papers will be held Friday afternoon, if desirable.

Members desiring further information about the program should address Sidney Powers, Box 2022, Tulsa.

The attention of the members is called particularly to the following :

Papers, in order to be acceptable for presentation at the convention and publication in the *Bulletin*, must be prefaced by a brief abstract, preferably less than 250 words, stating the principal points of the paper and the conclusions reached. An original typewritten sheet of this abstract should be mailed before the meeting to J. P. D. Hull, Business Manager, Box 1852, Tulsa, so as to reach him not later than March 15. Papers presented before the Association are considered the Association's property, and they are not to be published elsewhere than in the Association *Bulletin*, except by arrangement with the Business Manager.

Information about hotel accommodations will be furnished in a special communication from the local committee. Advance inquiries should be directed to G.C. Potter, Tidal Oil Company, 602 South Cheyenne, Tulsa.

The annual banquet is being arranged in separate groups this year, by states, colleges, or other affiliations, according to the desire of the different members. Members desiring to arrange group banquets should address Richard Hughes, Cosden Building, Tulsa.

Railroad transportation is in charge of A. W. Duston, 235 Kennedy Building, Tulsa. In order to secure the expected rate of a fare and a half for the round trip, members must get a receipt from the railroad agent from whom purchased. Unless the railroad thus sells a specified number of tickets, the special rate cannot be secured. The same conditions of securing receipts when purchasing tickets and having the tickets validated upon arrival in Tulsa will apply this year as last year.

Plan to attend. Reserve your room. Specify preference of affiliation for banquet. Authors, send in your abstracts. Buy your special-rate ticket. Come to Tulsa!

THE EXECUTIVE COMMITTEE

PROGRAM OF THE SECTION OF PALEONTOLOGY

The Section of Paleontology of the Association will hold its meeting with the parent-association at Tulsa in March. Paleontologists are invited to present papers at that meeting. The papers may be on either pure or applied paleontology, particularly on micro-paleontology or its application to the solution of geological problems. Titles and abstracts of papers should be sent to the Chairman of the Program Committee of the Association, Sidney Powers, Box 2022, Tulsa, Oklahoma, or to the Chairman of the Sectional Program Committee, J. J. Galloway, Columbia University, New York City.

Paleontologists are also invited to submit papers for publication in the *Journal of Paleontology*, which was proposed at the Dallas meeting and funds for which have now been secured. It is planned to have the first number of the *Journal* published early in 1927. Papers may be submitted ready for publication to Editor Galloway, or to the Secretary of the Section, M. A. Hanna, P. O. Drawer C, Houston, Texas.

THE MID-YEAR MEETING IN NEW YORK

The brilliant symposium on foreign oil fields arranged by the local committee for the fall meeting of the Association attracted a somewhat exceptional group of members to New York City, November 15, 16, and 17, 1926. Geologists registering from both Americas

came to hear, and to take part in, a program that was world-wide in its scope. The sessions were held in the southeast ballroom of the Hotel Pennsylvania. President Alex W. McCoy presided. An unusual and important part of the meeting was the Monday night session of the Association held in the auditorium of the Engineering Societies Building. A small but distinguished group of speakers delivered some remarkably interesting and valuable discussions on the subject of "The Theory of Continental Drift." It is expected that these special contributions will be printed as a separate volume of the Association's publications.

W. A. J. M. van der Gracht, who led the symposium on continental drift, and the members of the local committee on arrangements, are to be congratulated on the success of the meeting.

No papers were scheduled for the last two afternoons of the meeting, thus affording the visitors to the metropolis some time for entertainment and sightseeing. On Monday noon the ladies were entertained at luncheon at the Ritz-Carlton Hotel, followed by a theater party. Mrs. E. DeGolyer and Mrs. C. H. Wegemann were in charge of these arrangements. On Tuesday evening the specially arranged dinner-dance was enjoyed in the Hotel Pennsylvania.

The following papers were read at the sessions:

Probable Effect of Venezuelan Oil Production on the Crude Oil Situation
Michael O'Shaughnessy
Tectonics of the Maracaibo Basin (read by Fred H. Kay) . . . . . R. A. Liddle
Life in Venezuela . . . . . Fred H. Kay
Health Problems in the Venezuelan Oil Fields from the Standpoint of Preventive Medicine . . . . . E. P. DeBellard
General Oil Geology of Colombia (read by J. T. Duce) . . . . . A. Hamilton Garner
Notes on the Stratigraphy and Structure of Colombia . . . . . James Terry Duce
Petroleum Resources of Russia . . . . . Arthur H. Redfield
The Oil Prospects of Siam (read by W. B. Heroy) . . . . . Wallace Lee
Oil Possibilities of Northeastern China . . . . . Frederick G. Clapp and Myron L. Fuller
Canadian Oil Fields (introduced by O. B. Hopkins)
G. S. Hume, *Director*, Geological Survey of Canada
Oil Fields of New Zealand . . . . . Frederick G. Clapp
Oil Possibilities of Peru . . . . . Arthur Iddings
Notes on the Oil Fields of Persia and Mesopotamia . . . . . E. W. Shaw
Oil Development in Spain . . . . . A. Faison Dixon
The Geology and Oil and Gas Possibilities of Palestine and the Sinaitic Peninsula
F. Julius Fohs
Oil Possibilities of the Desert Basin of Northwest Australia . . . . . Frederick G. Clapp
Oil Possibilities of the Northwest Basin of West Australia . . . . . Frederick G. Clapp
Oil Possibilities of Australia . . . . . Frederick G. Clapp
Explorations East of the Andes in Ecuador . . . . . Joseph H. Sinclair and T. Wasson
Geology of the Santa Elena Area, Ecuador . . . . . O. B. Hopkins
Notes on the Geology of the Peninsula of Yucatan . . . . . J. J. Galloway
The Search for Oil in New Guinea, (introduced by F. G. Clapp; read by Sidney Powers)
Arthur Wade
The Theory of Continental Drift . . . . . W. A. J. M. van der Gracht
Hypothesis of Continental Displacement . . . . . Charles Schuchert
Discussion . . . . . R. Longwell

Discussion . . . . W. Bowie
Discussion . . . . C. P. Berkey
Discussion . . . . A. C. Lawson

The following papers were presented by title:

Notes on the Oil Fields of Venezuela . . . . J. B. Burnett
Geology of the State of Falcon, Venezuela . . . . Samuel Wiliston and C. R. Nichols
Geologic Mapping by Airplane Photography . . . . E. A. Hall
Oil Fields of Egypt . . . . H. Sadek
Oil Production by Japan in Sakhalin (introduced by R. E. Somers) . . . . I. P. Tolmachoff
Oil Fields of Russian Sakhalin . . . . Giichiro Kobayashi
Rock Pressure . . . . W. B. Heroy
Notes on the Oil Development of the Argentine (introduced by A. Hamilton Garner) Juan E. Rassmuss
The Petroliferous Belt of Central-Western Mendoza Province, Argentine . . . F. H. Lahee
Geology of Eastern Hidalgo and Vera Cruz . . . . R. H. Palmer
Age of the Tantoyuca Formation . . . . J. V. Dorr
Notes on the Geology and Oil Fields of Poland . . . . A. E. Fath

The general committee for the New York meeting was composed of the following: E. DeGolyer, general chairman; C. H. Wegemann, chairman, program committee; A. H. Garner, chairman, finance committee; W. B. Heroy, and L. C. Snider.

The committee on resolutions presented the following, which were accepted and passed:

JAMES FURMAN KEMP

WHEREAS, The American Association of Petroleum Geologists learns with infinite regret of the death of Dr. James Furman Kemp, professor of geology in Columbia University, and a member of this Association,

Be it hereby resolved, That the Association express its sense of the profound loss to geologic science and to the spirit of scientific investigation through the death of Dr. Kemp.

And be it hereby resolved, That the members of the Association extend to the family of Dr. Kemp their deepest sympathy in this bereavement.

Be it further resolved, That this resolution be incorporated in the minutes of this meeting of the Association and that a copy be sent to the family of Dr. Kemp.

(*Signed*) W. B. HEROY, *Chairman*
F. W. DEWOLF
J. P. D. HULL,
Committee

RESOLUTIONS

Be it resolved, That we, the members of the American Association of Petroleum Geologists in meeting assembled at New York City on November 17, 1926, hereby express our appreciation and hearty thanks to all those who have made this meeting so profitable and enjoyable to the members and their wives in attendance, and specifically to the following:

1. The local committee for assembling the foreign symposium and other papers of marked interest, and for the perfect arrangements and entertainment provided.

2. Those corporations and individuals whose financial support has made the meetings possible and whose co-operation has been acknowledged in detail in the p.inted program of the meetings.

3. The American Institute of Mining and Metallurgical Engineers, for the co-operation and facilities cordially extended.

4. The Hotel Pennsylvania, for the hospitality extended by its management.

And be it further resolved, That copies of these resolutions be submitted to the American Association of Petroleum Geologists for publication in the "Round Table" of the Association *Bulletin*, and be sent to those specifically mentioned.

(*Signed*) W. B. HEROY, *Chairman*
F. W. DEWOLF
J. P. D. HULL
Committee

The following members registered at the New York meeting:

Aurin, F. L., Ponca City, Okla.
Bain, H. F., New York City
Bateman, A., New Haven, Conn.
Binney, E., Jr., New Haven, Conn.
Bowen, C. F., New York City
Brokaw, A. D., New York City
Burnett, J. B., Maracaibo, Venezuela
Cheney, M. G., Coleman, Texas
Clapp, F. G., New York City
Cobb, Margaret C., New York City
Crandall, Roderic, Port Washington, L.I., N.Y.
Davis, Ralph E., Pittsburgh, Pa.
DeGolyer, E., New York City
DeWolf, F. W., Houston, Texas
Dixon, A. Faison, New York City
Duce, James T., New York City
Eagles, Homer M., New York City
Farrell, Agnes M., Washington, D.C.
Fohs, F. Julius, New York City
Foraker, William S., Pittsburgh, Pa.
Galloway, J. J., New York City
Garner, A. H., New York City
George, W. O., New York City
Gretzinger, William, White Plains, N.Y.
Hamilton, C. M., New York City
Harkness, R. B., Toronto, Canada
Harrison, Thomas S., Denver, Colo.
Heroy, William B., White Plains, N.Y.
Hinds, Henry, St. Paul, Minn.
Hopkins, Oliver B., Toronto, Canada
Hull, J. P. D., Tulsa, Oklahoma
Huntley, L. G., Pittsburgh, Pa.
Iddings, Arthur, Toronto, Canada
Jeffreys, G., New York City
Kay, Fred H., New York City
Kellum, Lewis B., Tampico, Mexico
Knapp, Arthur, Philadelphia, Pa.
Knappen, R. S., Pittsburgh, Pa.
Lesniak, S. W., Puerto, Mexico
Lewis, J. Volney, New York City
MacKay, Hugh, Sapulpa, Okla.
Manning, Van H., Forest Hills, N.Y.
Mather, Kirtley F., Cambridge, Mass.
McFarland, R. S., Tulsa, Okla.
McKee, H. Harper, New York City
McCoy, Alex W., Denver, Colo.
Naramore, C., New York City
Nash, Howard F., Polson, Mont.
Pogue, Joseph E., New York City
Postley, Olive C., Washington, D.C.
Powers, Sidney, Tulsa, Okla.
Rade, Henry S., New York City
Radler, Dollie, Tulsa, Okla.
Richards, Raymond, New York City
Ridings, Lowell J., New York City
Ruby, Glen M., Alta, Canada
St. Clair, Stuart, New York City
Sands, J. M., Bartlesville, Okla.
Schuchert, C., New Haven, Conn.
Shaw, E. W., New York City
Singewald, Joseph T., Jr., Baltimore, Md.
Small, Walt M., Tampico, Mexico
Smith, George Otis, Washington, D.C.

Snider, L. C., New York City
Trager, Earl A., Ponca City, Okla.
Thom, W. T., Washington, D. C.
Trask, Parker D., Washington, D. C.
Van der Gracht, W. A. J. M., Ponca City, Okla.
Walters, Ray P., Bucarest, Roumania
Wasson, T., Chicago, Ill.
Weeks, L. G., New York City
Wegemann, C. H., New York City
Weinzierl, John F., Houston, Texas
Weinzierl, Laura Lee Lane, Houston, Texas
White, David, Washington, D.C.
White, Luther H., Tulsa, Okla.
White, M. P., New York City
Willis, C. G., Ponca City, Okla.
Winchester, Dean E., Denver, Colo.

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

David Donoghue, director of the Texas Pacific Coal and Oil Company, Fort Worth, Texas, spent several days in Tulsa last November.

Glen M. Ruby is in charge of exploratory work and personnel of the Marland Oil Company of Colorado party investigating the oil possibilities of Canada. About a dozen geologists from Colorado, Oklahoma, and California make up the party. E. V. Whitwell, of Denver, will be in charge of the geological work in the prairie provinces and also exercise general supervision over the geological staff. Ben F. Hake, of California, is in charge of the geological work in the McKenzie River basin, which offers a separate problem in transportation. Mr. Ruby's address is 11618 One-hundredth Ave., Edmonton, Alberta.

Arthur Wade, formerly a geologist for the government of Australia, is established as consulting geologist in London.

W. C. Mendenhall, chief geologist of the U. S. Geological Survey, spent the autumn in Japan.

N. H. Darton, of the U. S. Geological Survey, spent the winter in Venezuela.

Oliver B. Hopkins, chief geologist of the Imperial Oil Company of Toronto, Canada, left for South America in January.

A. C. Veatch, of the Sinclair Exploration Company, spent November in Europe.

H. D. Miser, of the U. S. Geological Survey, is planning to spend the summer of 1927 in the Ouachita Mountains, Oklahoma.

J. A. MacDonell is spending the winter on a trip around the world.

J. P. Smith, formerly with the Humble Oil & Refining Company, has taken a position in the geological department of the Roxana Petroleum Corporation, at Shreveport, Louisiana.

William Chisholm, formerly in the geological department of the Roxana Petroleum Corporation, has been appointed head of the Minerals Division of the Louisiana Department of Conservation. Mr. Chisholm's headquarters will be in Shreveport, Louisiana.

A. E. Fath has been in Europe, making a geological examination that has kept him busy several weeks.

E. P. Philbrick has moved from the office of the White Eagle Oil & Refining Company at Denver, Colorado, to 318 Alexander Building, Abiline, Texas.

Phil B. Dolman, independent geologist of Tulsa, Oklahoma, has removed his offices and residence to San Angelo, Texas. Address, 18 N. Oakes Street; phone, 2104.

B. Coleman Renick has resigned from the U. S. Geological Survey to take a position with the Roxana Petroleum Corporation at Dallas, Texas.

W. A. Barth, of the Arkansas Fuel Oil Company, and Miss Mary Sage Brinkmann, both of Shreveport, Louisiana, were married November 3, 1926.

D. R. Semmes, associated with E. B. Hopkins, of New York, has opened an office in the Spencer Building, Cisco, Texas.

The Houston Geological Society is co-operating with Miss Julia Ideson, Librarian, Houston Public Library, in establishing a geological reference library at the Houston

Public Library to cover: (1) general geology, paleontology, and petroleum geology, (2) the geology of Texas and adjacent states, (3) paleontology. DONALD C. BARTON, president of the Houston Geological Society, and RAYMOND H. GOODRICH, chairman of the Library Committee, would be grateful if geologists who have written on any phase of the geology of Texas, Louisiana, Arkansas, Oklahoma, New Mexico, and Mexico would contribute their papers. Contributions should be sent to Miss Julia Ideson, Houston Public Library, Houston, Texas.

H. W. C. PROMMEL, recently of Wichita Falls, Texas, has moved his headquarters back to 731 South Downing Street, Denver, to keep in closer touch with developments in Utah. Mr. Prommel covers, in particular, the area of Utah, Colorado, and Wyoming.

The following officers were elected by the HOUSTON GEOLOGICAL SOCIETY for the coming year: President, DONALD BARTON; vice-president, ELIZABETH STILES; secretary-treasurer, JOHN VETTER. The society meets for an informal luncheon at the University Club at 12:30 P.M. on the first Friday of each month.

The engagement has been announced of MISS EMMA JANE KOFFMAN, of the Paleontological Laboratory, Humble Oil & Refining Company, to JOHN MILLER, paleontologist with the Texas Company.

DILWORTH HAGER, retiring president of the Houston Geological Society, is reported to be going to give a dance shortly for the Society, in conformity with a recently adopted resolution that the retiring president should hold a dance for the Society.

DONALD C. BARTON was recently transferred from the position of chief geologist, Rycade Oil Corporation, to that of chief of the magnetometric and gravimetric section of the Geophysical Research Corporation and consulting geologist to the Rycade Oil Corporation, with no change of address.

MISS KATHERINE HARRE, of the Houston office, Geophysical Research Corporation, was married November 4, 1926, to M. D. ANDRUS, observer, seismograph section, Geophysical Research Corporation.

MISS WINNIE MCGLAMERY, for the past three years graduate student in paleontology at Johns Hopkins University, has joined the Paleontological Laboratory, Humble Oil & Refining Company, Houston, Texas.

The Oklahoma Geological Map has been printed in two sections, and the total number of stones required for printing a complete map is forty. The edition of 8,000 copies will mean 320,000 printings.

O. L. DALLAS is employed by O. J. Connell in Midland, Texas.

F. P. GEYER has resigned as president of the Marland Oil Company of Texas, and as a director of the Marland Oil Company of Delaware.

E. W. SCUDDER, in charge of the geological work of the Gypsy Oil Company in Denver, visited their Tulsa office in November.

H. N. URI and FAY WEIMER, consulting geologists, have moved from Okmulgee to Shawnee, Oklahoma.

J. S. HUDNALL and G. W. PIRTLE have established an office as consulting geologists at Brownwood, Texas.

FREDERICK A. BUSCH, formerly of the Atlantic Oil Producing Company, is now with the Sinclair Oil & Gas Company in the Tulsa Office.

E. B. WORD, formerly of the Sinclair Oil & Gas Company, is now with the Barnsdall Oil Company in Tulsa.

H. D. EASTON, of Shreveport, Louisiana, is consulting geologist for the Amory

Petroleum Company, who recently drilled a gas well in Sec. 7, T. 13 S., R. 17 W., Monroe County, Mississippi; depth, 2,470 feet.

HUBERT K. SACKETT, formerly with the United States Treasury Department, is geologist for the Fisher Oil Company of Pittsburg, with headquarters in the Lynch Building, Tulsa.

JULIA A. GARDNER, of the U. S. Geological Survey, is working in Texas on the areal geology of the Tertiary for the geological map of the state, which is in preparation.

M. R. CAMPBELL is acting chief geologist of the U. S. Geological Survey in the absence of W. C. MENDENHALL.

J. MELVILLE SANDS, consulting geologist for the Phillips Petroleum Company, spent the fall in western Canada.

HARVEY BASSLER is chief geologist of the Standard Oil Company of New Jersey in Peru, with headquarters at Iquitos.

CHARLES SCHUCHERT, of Yale University, is spending the winter in the West.

THERON WASSON, chief geologist of the Pure Oil Company of Chicago, is planning a trip to South America.

R. P. WALTERS returned from Roumania the past fall for a visit to the United States.

JUAN E. RASSMUSS, consulting geologist of Buenos Aires, visited New York City in November.

ARTHUR IDDINGS, chief geologist for the International Petroleum Company in Peru, spent the fall in the United States.

JERRY B. BURNETT, chief geologist of the Lago Oil Company, visited New York in November for a conference with FRED H. KAY, assistant to the president of the Lago.

E. S. BLEEKER is chief geologist for the South American Gulf in western Venezuela.

HENRY HINDS, chief geologist for the Pantepec Petroleum Company of Venezuela, spent the fall in New York City.

H. H. MCKEE, of the firm Brokaw, Dixon, Garner & McKee, is spending the winter in Caracas with his family.

E. B. HOPKINS, consulting geologist, spent the fall in Venezuela.

RAYMOND C. MOORE has obtained leave of absence from the University of Kansas to engage in research work at Washington on oil geology under the auspices of the National Research Council.

R. D. TRASK is engaged in research work in Washington for the National Research Council.

MOWRY BATES died November 16 at Ocean Park, California.

HOWARD NASH, formerly with the Henry L. Doherty Company, is engaged in consulting work in New York City.

E. W. SHAW, of Mesopotamia, is visiting in New York City.

BARNABAS BRYAN, of New York City, has resigned from the Standard Oil Company of New Jersey.

C. F. BOWEN, chief geologist of the Standard Oil Company of New Jersey, returned from Buenos Aires in November.

W. M. SMALL, of Tampico, spent November in New York recovering from an attack of malaria.

SIDNEY PAIGE, geologist for the Esperanza Petroleum Company in Venezuela, has recovered from an attack of malaria.

A. C. LAWSON, of Berkeley, California, visited New York in November.

James F. Kemp, of Columbia University, died November 17 from heart failure.

Miss Agnes M. Farrell and Miss Olive C. Postley, of the U. S. Geological Survey, visited New York in November.

N. B. Winter, of the Atlantic Oil Producing Company, has been transferred from Shreveport, Louisiana, to Amarillo, Texas.

James B. Templeton and Roy A. Reynolds, associated with J. Elmer Thomas, are living at Cisco, Texas.

R. H. Palmer is engaged in consulting geological work at Seattle, Washington.

William Embry Wrather, of Dallas, Monroe G. Cheney, of Coleman, Texas, and C. W. Tomlinson, of Ardmore, Oklahoma, attended the Geological Society of America meeting at Madison, Wisconsin, in December.

Ralph A. ("Jack") Brant is geologist for the Shaffer Oil & Refining Company at Tulsa.

Hugh MacKay, of Sapulpa, returned home in November from a trip to Prince Edward Island, where the well of Henry L. Doherty & Company is shut down for the winter at a depth of about 4,127 feet. The well is located on Governors Island in Hillsborough Bay, south of Charlottetown.

E. R. Brockway is division geologist for the Ohio Oil Company in Illinois, with headquarters at Marshall.

Jon A. Udden has moved to Bentonville, Arkansas.

Dean E. Winchester, of Denver, has gone to Venezuela for the Sinclair interests. Roy Holloman is temporarily in charge of the Denver office.

Clyde M. Bennett, vice-president of the Louisiana Oil Refining Corporation at Shreveport, Louisiana, spent November in Trinidad for his health.

C. N. Gould was elected president of the Oklahoma Academy of Science at the annual meeting held at Stillwater, Oklahoma, November 28.

Memorial

MOWRY BATES

Mowry Bates, one of the pioneers in the geological history of the mid-continent field, died in Venice, California, on November 17, 1926.

For several years previous to his death, Bates was in failing health; in fact, his removal from Tulsa to California in 1922 was influenced entirely by his desire for a change in environment which he thought might benefit him in this regard.

Mowry Bates was born in Cleveland, Ohio, September 19, 1875. He was educated in the public schools of that city and of Hoboken, New Jersey. He attended Michigan Military Academy and Stevens College, and later took a special course in mining engineering at Columbia University. For several years prior to 1910 he was engineer and superintendent for different mining interests in Michigan, Colorado, Canada, and Cuba. At this time Oklahoma was assuming some prominence as an oil-producing state, and Bates, forsaking the mining field, came to Bartlesville, where he was successively roustabout, driller, and then geologist at a time when the three or four geologists who were then in the mid-continent field were looked upon as curiosities. He was connected with the Gypsy in these early days in Oklahoma, and from 1912 to 1915 he served with the Gulf Refining Company of Louisiana, where, at Shreveport in 1915, he became chief geologist for the company.

Bates was one of the first to apply subsurface geology in the quest for oil, and while in Shreveport he constructed a map of Louisiana, contoured on the Nacatoch sand. His paper, "A Concrete Example of the Use of Well Logs," published in the *Transactions of the American Institute of Mining Engineers* in 1918, explained the methods used in this early work.

In 1915 Bates returned to Tulsa and formed a partnership with Dorsey Hager, which was dissolved in 1918. From 1918 to 1922 he was associated with Bernard H. Lasky in consulting practice, when his health forced him to seek a change in California.

Bates, while in Tulsa, was frequently consulted on economic problems in connection with the industry by the Mid-Continent Oil and Gas Association, the Oil Men's Protective Association, and kindred organizations, and was chosen by the Mid-Continent Oil and Gas Association in 1920 to assemble the data upon which it relied to refute the charges of profiteering in the investigation of the oil industry conducted by the Federal Trade Commission following the passage of the Dyer Resolution.

He was a member of the American Association of Petroleum Geologists, the American Institute of Mining and Metallurgical Engineers, and the American Association of Engineers. He was also a member of Petroleum Lodge No. 474, A.F. and A.M., Oklahoma Consistory No. 1, Scottish Rite Masons, and Akdar Temple of the Shrine.

"Mowry," as he was known to everyone, was characterized by a buoyant spirit of cheer and of optimism for which he was always loved. Vision, industry were his, and a sterling honesty. It is to be regretted that, handicapped by the burden of ill health, he could not fulfill the promise of his pioneer days in the mid-continent field.

He is survived by a widow and two children.

BERNARD H. LASKY

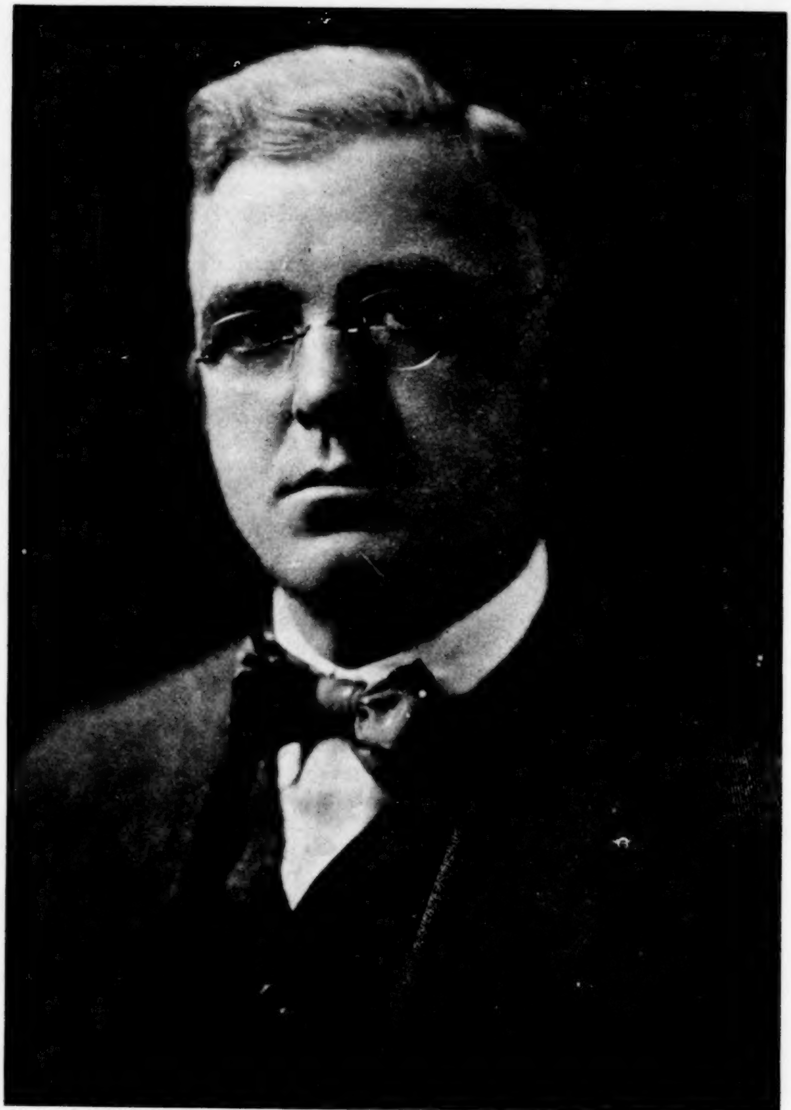

Photo by J. L. Rivkin

MOWRY BATES

WARNER WILSON NEWBY

Warner Wilson Newby died at Ponca City, Oklahoma, October 25, 1926, from injuries received a few hours before in an automobile accident. He was returning to his home in Tulsa when his car turned over at one of the dangerously sharp turns on the road between Ponca City and Burbank.

Although born at Denver, Colorado, February 23, 1898, Warner Newby received his early education at San Antonio, Texas, graduating from the high school there in 1914. He then entered the University of Oklahoma, finally taking an A.B. degree in 1921, after the interruption of the war and after working a year and a half for the Gypsy and Roxana oil companies. He enlisted in the United States Marines at the age of twenty, and had completed the ground-work for flying when the armistice was signed.

During his last days at the University, he was ordained to the Christian ministry and contemplated foreign missionary work, but was never able to carry out this intention. After graduation he joined the geologic staff of the Roxana Petroleum Corporation and remained with that organization to the time of his fatal accident.

Warner Newby was married to Elsie Faye Dougherty, of Oklahoma City, Oklahoma, in 1922. Besides his wife and two children, he leaves his parents, Mr. and Mrs. H. W. Newby, three brothers, Errett R., John A., and J. B., and two sisters, Mrs. Frank Buttram and Jessie D. Newby. Although the youngest of his family, he was the first to go.

He was a member of the Sigma Nu fraternity and the Kappa Tau Pi religious order. His American Legion connection was with the Neil Huff post at Ponca City. He had been a member of the American Association of Petroleum Geologists for more than five years.

Warner Newby's fine character and keen mind were most appreciated by those who knew him best. The commercial nature of his work and the lack of time prevented his publishing much, but he was a brilliant geologist and gave promise of going far in his chosen profession.

T. K. HARNSBERGER

FREDERICK BEVAN TOUGH

Frederick Bevan Tough, production superintendent for Humphreys Corporation, Houston, Texas, lost his life October 24 in a fire in the oil field at Sour Lake, Texas. Previous to his connection with the Humphreys Corporation, Mr. Tough was chief petroleum engineer with the United States Bureau of Mines, Washington, D.C., and had long been active in oil field work and in engineering and geological societies concerned with petroleum technology.

Born in Baltimore, December 3, 1885, Mr. Tough was educated at Johns Hopkins University and graduated in engineering at Columbia School of Mines. His first important work after leaving school was with the Kern Trading and Oil Company, a Southern Pacific subsidiary, at Bakersfield, California. Later he was employed as petroleum engineer in the United States Bureau of Mines, and became superintendent of the Rocky Mountain office, which supervised all drilling and production on the public lands. Following the war, Mr. Tough was made chief of the Petroleum Division of the Bureau, a position from which he resigned in order to enter commercial work with the Humphreys Corporation.

As a young man, Mr. Tough was active in athletics, and played football, tennis, and lacrosse. His love of the out-of-doors was unusual, and his sportsmanship and friendly relations with his subordinates endeared him to them to an unusual degree. He will be remembered for his ability, courage, and loyalty.

FRANK W. DE WOLF